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AN INTRODUCTION TO THE *True ASTRONOMY:*

OR,

Aſtronomical Lectures,

Read in the

Aſtronomical School

OF THE

UNIVERSITY of *OXFORD.*

By *JOHN KEILL*, M. D. Fellow of the *Royal-Society*, and Profeſſor of *Aſtronomy* in that Univerſity.

The Works of the Lord are great, ſought out of all them that have Pleaſure therein, Pſal. CXI. v. 2

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TO

His Grace *JAMES* Duke

OF

CHANDOS.

May it pleaſe your Grace,

AMong all the Mathematical Sciences which have been continually improved, and are daily improving in the World, the firſt Place has, as it were, by general Conſent, been always given to Aſtronomy. *And ſuch has been either the good Fortune of the Science, or the Virtue of Mankind, that the greateſt and moſt eminent Perſons in all Ages and Nations, have been Patrons and Encouragers of this Study above all others.*

May it pleaſe your Grace, therefore to take this Book *into your Protection, ſince whatever may be wanting, either in the Work or the Author, to recommend it to your Favour, will abundantly be ſupplied by the* Dignity *of the Subject.*

For *to whom can I ſo properly ſend a Treatiſe of the Stars and Heavenly Motions, as to a faithful and zealous Servant of that Heavenly King,* who knoweth the Number of the Stars, and calleth them by their Names. *So remarkable is your Grace's Zeal for the Service and Honour of God, that you took particular Care to adorn* his Houſe *before you would lay the Foundation of your* own. *Nor did your Care extend only to the Orna-*

ments of the Temple, but likewiſe, and more eſpecially to the Decency of the Worſhip: You call'd Muſick in to excite Devotion; Muſick being the Delight and Employment of the Heavenly Choir.

You, My Lord, are the publick and ſtanding Mark of all Mens Admiration, the beautiful Patern which all deſire to imitate, tho' few can hope to equal. In publick Affairs what Stateſman more able? In domeſtical Management, what private Man more expert? In the conſtant ſtating and exact keeping of Accompts, no Body more Provident, no Body more Frugal. In Expences, no Body more Liberal: In Largeſſes, no Body ſo Magnificent.

So great is your Affection to Learning and the Learned, that while you make yourſelf Maſter of every Art, you give Matter and Encouragement to every Artiſt. To the particular Science which is the Subject of this Book your Grace is ſo Eminent, ſo Benificent a Patron, that in the ſtately and beautiful Structure of Cannons, *Aſtronomers will find every thing for the Improvement of their Knowledge; Inſtruments worthy of the Science, and an Obſervatory worthy of its Lord.*

The Book I now preſent is a Tranſlation of thoſe Aſtronomical Lectures, which were honoured with your Grace's Name at their firſt Publication, in the Language they were read in at the Univerſity of Oxford. *The*

Verſion was made at the Requeſt and for the Service of the fair Sex, and particularly for the Service of the great Ornament of her Sex the Dutcheſs of Chandos. *It is no Flattery to the Ladies to ſay that ſuch of them as delight in Arts and Sciences, as to Quickneſs of Perception and Delicacy of Taſte, are equal, if not ſuperior to Men; and it is no Affront to the moſt refined of either Sex to ſay, there is not a finer Genius than my Lady Dutcheſs.*

May every Star in Heaven ſhed its kindeſt Influence on both your Heads. And may you long continue to enjoy that Affluence, which, like the Rays of the Sun, ſcatters Light and Warmth to all round you.

This, my Lord, is a general Wiſh, becauſe it is for the General Good of Mankind, particularly of him who is with the deepeſt Senſe of Gratitude,

Your Graces

moſt faithful

and moſt humble Servant,

JOHN KEILL.

THE PREFACE.

AMONG all the Gifts and Benefits the moſt bountiful God has moſt plentifully beſtowed on Mankind, thoſe are in the firſt place Valuable, which conſiſt in the Improvements of the Mind by Arts and Sciences. And as among the Sciences there are none which *Aſtronomy* comes behind upon the Account of its Antiquity, and the Pleaſure that attends the Study of it; ſo it will yield to none of them on the account of its uſefulneſs, and the Advantages it affords to Human Life. By it we diſcover the wonderful Harmony of Nature, wherewith the Frame and Structure of all Created Beings are linkt and knit together, to conſtitute the great Machine of the Univerſe. *Aſtronomy* teaches us to obſerve and diſcover the Motions of the Heavenly Bodies, and it weighs and conſiders the Force and Vigor by which they circulate in their Orbs. It is a Science which the greateſt Heroes from the beginning of the World have taken Pleaſure to Study and improve; ſo that it was always eſteemed as a Science fit for Kings and Emperors to employ themſelves in. On which account the *Chaldean* Wiſemen and Philoſophers were always reverenced and favoured by the Antient Kings, who thought it abſurd that any ſhould Govern the World, who knew not what the World was.

THE Excellency of this Science appears from this, that their is no Knowledge which is attained by the Light of Nature, that gives us truer and juſter Notions of the Supreme and Almighty God the Maker of both Heaven and Earth, than it does. None furniſhes us with ſtronger Arguments by which his Exiſtence is demonſtrated; nothing ſhews more his Power and Wiſdom, than the Contemplation of the Stars and their Motions. That Prophet as well as King, the Holy *David*, tells us, that *The Heavens declare the Glory of God, and the Firmament ſheweth his handy Work.* And again, *The Heavens declare his righteouſneſs, and all the People have ſeen his Glory.*

MARCUS Tullius Cicero who was guided only by the Light of his own Reaſon, had the ſame Sentiments. *Nothing ſays he, is more evident, nothing plainer when we look up to the Heavens, and contemplate the Bodies there, than that there is a Deity of moſt Excellent Wiſdom who Governs them.* What is there that more raviſhes the Mind of Man into an Admiration, Reverence and Love of God, than ſo many and ſo great Bodies endowed with Heavenly Light, moſt beautiful to the Eye, and when contemplated, moſt delightful to the Underſtanding. Their mutual intercourſes, moſt regular Motions, their certain and determined Circulations, and their Returns and Periods ſettled by a Divine Law, in an admirable Harmony, make manifeſt to us the immenſe Power, Wiſdom and Providence of their Maker; which when we conſider we muſt neceſſarily acknowledge, Reverence and Celebrate the Author and Contriver of all theſe things.

BESIDES *Aſtronomy* with its Sublime Speculations, about ſo many and ſo large Bodies, and at ſuch immenſe diſtances, does wonderfully pleaſe and recreate the Mind.

ASTRONOMY for the certainty and evidence of its Demonſtrations, is not Inferiour to *Geometry*;

try; its uſefulneſs is manifold, and the Amplitude of its *Subject* is ſo large that it comprehends nothing leſs than the World it ſelf. For as among all the liberal Sciences there are none that contemplates Objects more in Number, greater in Quantity, or at longer diſtances from us than *Aſtronomy*; ſo likewiſe there are none in which there ſtill remains fewer difficulties to be explained, Objections to be anſwered, or Scruples to be removed, than there are in *Aſtronomy*; and no Science has yet attained ſo great a degree of Perfection as it has.

IN moſt of the other Arts there are ſeveral Inextricable Labyrinths; many ſtrange Objections are raiſed, and unanſwerable Arguments which do ſo confound the Mind, that like thick Clouds, they ſtop all further Proſpect and diſcovery. But the Motions of the Heavenly Bodies are now certainly known, and their cauſes demonſtrated, and the reaſon of all the *Phænomena* of the Heavens are exactly underſtood.

THE ſmalleſt Stars we can ſee, tho' they be at an unmeaſurable diſtance from us, yet have their Longitudes and Latitudes exactly determined, their proper places ſettled and are all reduced into Catalogues; tho' at the ſame time the Science of *Geography*, or a Deſcription of our own Habitation, is ſo imperfect, that we have an exact Determination of the Longitudes and Latitudes of but a very few Places; there ſtill remaining many *Unknown Lands* and Countries, that have not as yet been diſcovered: And there are now great and far extended *Continents*, of which we ſcarcely know any thing beſides their Coaſts and Shoars. And what is ſtill more ſtrange, in our little Provinces and Counties which we daily Travel over, their are many Towns and Cities whoſe Poſitions are ſtill uncertain; as is plain from the many *Geographical* Maps of them, which contradict each other.

THE *Aſtronomers* foretel, for many Ages to come, the Eclipſes of both Sun and Moon, their Quantities and Durations: The Conjunctions, Oppoſitions and mutual Aſpects of the Planets, and what will be the diſtances of all the Stars from the Pole at any time: Whereas there is no Man ſo well skilled in *Meteorology*, as can certainly foretel what will be the State and condition of our Atmoſphere for the very next Day, and yet it reaches but a few Miles from us: we are unable to judge whither we ſhall have fair Weather or foul, calm or ſtormy, or even ſo much as to foreſee from what Point the Wind will blow. And this is no wonder, ſince the cauſes from whence theſe Effects ariſe are unſearchable.

NO *Philoſopher* has ever yet diſcovered the Figures of the ſmall parts of Matter, or the Texture, Intervals, Form and Compoſition of the parts of the moſt common Plant. Nor has any Phyſician yet found out the reaſon of the Virtues and Operations by which their Medicines affect Human Bodies. And even in all Animated and Vegetable Bodies, the Fountain and firſt Principle of Life and Action is unſearchable, and looks like a Myſtery much beyond the reach of our Underſtanding, which Knowledge perhaps in this Life is never to be attained. But *Aſtronomers* in their proper Science meet with no ſuch difficulties, they contemplate not the Natures, but the Motions of the Celeſtial Bodies, and they clearly account for the Phænomena or Appearances that ariſe from thence; they not only determine what ſort of Motion the Planets have, and in how large a compaſs they circulate; but they likewiſe ſhew us the crooked Tracts in the immenſe Regions of Space which the wandering Comets take; they can give us the *Geometrical* Properties of their Orbits, and the Laws which they obſerve in deſcribing them. The *Aſtronomers* are not ignorant where and when the Planets are at their furtheſt diſtance from the Sun, and participate the leaſt of his heat and light; from whence they return, and are conſtantly quickned in their Motions by the Sun, who draws them towards himſelf, 'till they come to thoſe parts of Space, where they make their neareſt approach to him, enjoy moſt of his heat and light, and are actuated by the greateſt force of their own Gravity.

MOST of the Diſcoveries we have related were known to the *Aſtronomers* of former Ages. But our Times, and this our Country of *Britain*, have had the happineſs to produce a *Genius* of a Divine Nature and extraordinary Qualities; I mean the Great Sir *ISAAC NEWTON*, who, beſides his innumerable other wonderful Inventions, has diſcovered the Fountain and Spring of all the Celeſtial Motions, and the Great Law which is Univerſally diffuſed thro' the whole Syſtem of Nature, which the Almighty and Wiſe Creator has commanded all Bodies to obſerve, *viz.* That every Particle of Matter attracts each other in a reciprocal duplicate Proportion of its diſtance.

THIS Law is, as it were, the Cement of Nature, and the Principle of Union, by which all things remain in their proper State and order; it detains not only the Planets, but the Comets within their due bounds, and hinders them from making excurſions into the immenſe Regions of Space; which they would do if they were only actuated by a Motion once implanted in them, which naturally they would always preſerve, according to the Principal Law of Motion.

WE are obliged to the ſame Gentleman for the diſcovery of the Law that regulates all the Heavenly Motions, ſetts bounds to the Planets Orbs, determines their greateſt Excurſions from the Sun, and their neareſt approaches to him. To this Sublime Genius we owe, that now we know the cauſe why ſuch a conſtant and regular Proportion is obſerved by both Primary and Secundary Planets in their Circulations round their Central Bodies, in comparing their diſtances with their Periods; and why all the Celeſtial Motions are ſtill continued in ſuch a wonderful regularity,

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Harmony and order. The ſame incomparable Perſon having a compleat Knowledge of the Laws of Nature and Motion, has from them furniſhed us with a new Theory of the Moon, which accurately anſwers all her Inequalities, and accounts for them by the Laws of Gravity and Mechaniſm; ſo that now the Moon's place, computed by the Rules of this New Theory, does not ſenſibly differ at any time from what it is obſerved to obtain in the Heavens, which does exceed the hopes and Expectations of our *Aſtronomers*; ſo that we have now a Proſpect of improving our Navigation, by finding from Obſervations of the Moon, the Longitude of a Ship at Sea: A *Problem* of great uſe, whoſe Solution is much to be deſired, and for which there are very ample Rewards allowed.

THERE is nothing that does more ſhow the force and Penetration of Human Underſtanding, than theſe great and wonderful diſcoveries. There is no more certain way of comprehending the Prodigious bulk of the whole Mundane Fabrick, or the amazing Beauty of ſo Divine a Structure, and the Infinite Wiſdom of its Divine contriver; than by conſidering theſe Laws which are lately diſcovered. From them we learn to have a moſt noble and magnificent Notion of the whole Syſtem of Nature. Now we are aſſured that this Earth we Inhabit, is but a ſmall and inconſiderable part of a Glorious Fabrick: Since there are almoſt Infinite Worlds, created by a Supreme and an Almighty Being, which are prodigiouſly larger than ours, in the diſpoſing and governing of which the ſame Being exerciſes his Infinite Power and Wiſdom. *It is He who ſpoke the Word, and the Heavens were made: He commanded and they were created. He hath made them faſt for ever and ever. He hath given them a Law which ſhall not be broken.*

ASTRONOMY is not only uſeful, as it improves the Mind, and by its moſt delightful Speculations, increaſes the Force and Penetration of the Underſtanding: But it is likewiſe a conſiderable Help to the perfecting of other Arts and Sciences. In how great Darkneſs would the *Geographers* the *Chronologiſts* wander, were they not aſſiſted with Light from *Aſtronomy?* To it is owing, that we know the Figure and Magnitude of the Earth, and find out the Situations and Diſtances of Places. We learn from it the true Meaſure of the Year, and can give an Account of Actions according to the true Order of the Times in which they happen'd. Hence is evident how uſeful *Aſtronomy* is to Human Affairs; for without it we could have no *Geography* nor *Chronology*, and conſequently no certain Account of Hiſtory,

BUT among all the Arts and Sciences, there is none that has receiv'd greater Improvements from *Aſtronomy* than *Navigation* has done; for by our Knowledge in it we can carry our Ships through the vaſt Ocean in a right Courſe, tho' there is no Tract to be ſeen, and viſit the utmoſt Regions of the Earth. Hence ariſe the Advantages of Trade and Commerce; ſo that whatever Things other Countries afford, that are either precious or delightful, we receive and enjoy without the Inconveniencies of intemperate Heats or Colds, to which thoſe Countries are liable. It is owing to our Skill in Navigation, that our *Britiſh* Monarchs have obtained the Sovereignty of the Seas: So that there is no Nation, at what Diſtance ſoever, but what are kept from doing Injuries to our Countrymen, by the Terrors of a *Britiſh* Fleet.

AS the Art of Sailing does, in a great Meaſure, depend on the Knowledge of the Stars; ſo the impetuous and ambitious Deſires of Kings and Princes, to diſcover unknown and foreign Countries, inclined them to cultivate *Aſtronomy*. The firſt and chief of all the Sailors was *Neptune*, who, upon the Account of his Skill in this Art, was celebrated as God of the Ocean. His Son *Belus*, being an *Aſtronomer*, by his Knowledge therein, carried the Inhabitants of *Lybia* into *Aſia*, where he inſtituted Colleges of *Aſtronomers*; for

Diodorus in the firſt Book of his Hiſtories writes thus: *It is reported*, ſays he, *that the* Egyptian Belus, *the Son of* Neptune *and* Lybia, *brought a Colony to* Babylon, *and there he inſtituted Prieſts, whom the* Babylonians *call* Chaldeans; *who, after the manner of the* Egyptians, *were to obſerve the Stars.* Before his Time, there was *Atlas* King of *Mauritania*, a great *Aſtronomer*, who firſt ſhew'd us the Doctrine of the Sphere. And therefore *Virgil* introduces *Jopas* ſinging what *Atlas* had taught Mankind,

——— Docuit quæ maximus Atlas,
Hic canit errantem Lunam Soliſq; labores.

SO *Uranus*, King of the Country ſituated on the Shore of the *Atlantick* Ocean, for his Skill in *Aſtronomy*, is ſaid to have been deſcended from the Gods. *Zoroaſter* a *Perſian* Philoſopher is celebrated by all Antiquity, as a skilful *Aſtronomer*. And the Honour and Dignity of this Science was had in ſo great a Reputation, as to be called the *Royal Science*, being that Kings were moſt delighted by it above all others. For the Kings of *Africk* and *Syria* firſt invented and improved it, and that long before it was known in *Greece*. This *Plato* acknowledges in his Dialogue, which he call's *Epinomis*. *The firſt*, ſays he, *who obſerved theſe things, was a* Barbarian, *who liv'd in an ancient Country, where, upon the account of the Clearneſs of the Summer Seaſon, they could firſt diſcover them, ſuch as* Egypt *and* Syria, *where the Stars are clearly ſeen, there being neither Rains nor Clouds to hinder their Proſpect. And becauſe we are more remote from this Summer clearneſs of Weather than the* Barbarians, *we came later to the Knowledge of theſe Stars.* So *Lucian* tells us, *That the* Ethiopians *firſt took Notice of the Heavenly Motions, and by finding the Cauſes of the Lunations, they knew that the Moon had no proper Light of its own, but borrow'd it from the Sun.* However, it is certain that *Aſtronomy*, from the very beginning was cultivated and improved by the Eaſtern Nations. For if we may believe *Porphyry*, when *Alexander* took *Babylon*, *Caliſthenes*, at the deſire of *Ariſtotle*, carried from that City the Obſervations of 1903 Years, which brings the beginning of theſe Obſervations to 115 Years after the Flood, and 15 Years after the building of *Babel*. *Pliny*, in his Natural Hiſtory relates, that *Epigenes* affirmed that the *Babylonians* had Obſervations of 720 Years, all graven upon Bricks. And *Achilles Tatius*, in the beginning of his Introduction to *Aratus's Phænomena*, informs us, "That the *Egyptians* were the firſt who meaſured "the Heavens and the Earth; and their Science "in this Matter was engraven on Columns, and "by that means delivered to Poſterity. Yet the "*Chaldeans* take the Honour of the Invention to "themſelves, and aſcribe it to *Belus*." The *Greeks* had all their *Aſtronomical* Learning from *Egypt*: For *Laertius* owns that *Thales*, *Pythagoras*, *Eudoxus* and many others went to that Country to be inſtructed in the Sidereal Science: Theſe Men were not only the firſt, but the greateſt Philoſophers that *Greece* produc'd: And from the ſame Author, we know, that they who ſtaid longeſt in that Country, were moſt famous for their Skill in *Geometry* and *Aſtronomy*, after they return'd home: So *Pythagoras*, who liv'd in Society with the *Egyptian* Prieſts ſeven Years, and was initiated into their Religion, carried home from thence, beſides ſeveral *Geometrical* Inventions, the true Syſtem of the Univerſe; and was the firſt that taught in *Greece*, that the Earth and Planets turn'd round the Sun, which was immoveable in the Center; and that the Diurnal Motion of the Sun and fixed Stars was not real, but apparent, ariſing from the Motion of the Earth round its Axis. At that Time no Body was eſteem'd as a Philoſopher, but who was well acquainted with the Mathematical Sciences.

BUT theſe Sciences were ſoon neglected by the Philoſophers that came after them, who much degenerating from their Predeceſſors, had ſo little

Care and Concern for the Mathematical Sciences, eſpecially *Aſtronomy*, that of all the Obſervations of Eclipſes, for the Space of near 2000 Years, that were ſent from *Babylon* by *Caliſthenes*, *Ptolomy* could not recover but a very few, the reſt being loſt by the Careleſneſs, Negligence, and want of Skill of thoſe Men, who ſhould have preſerv'd them. For theſe Pretenders to Philoſophy, having no Concern for the uſeful Parts of it, ſpent their Time about Trifles, and Diſputes of no Value, and in endeavouring to find out Sophiſms, whereby they would impoſe upon their own and the common Senſe of all Mankind; ſuch were *Zenos*'s Arguments againſt Motion, and moſt of the Philoſophers Diſputations againſt the Diviſibility of Matter *in infinitum*; whereas a little Knowledge of *Geometry* would eaſily have diſſolved all the Difficulties they could raiſe. But tho' *Aſtronomy* was thus baniſhed out of the Schools of the common Philoſophers, yet it was received and cultivated by ſome, tho' but a a few, eſpecially by the *Pythagorean* Sect, which flouriſh'd in *Italy* many Years, among whom was *Philolaus* and *Ariſtarchus Samius*. The *Ptolemy*'s Kings of *Egypt* were alſo great Patrons of Learning, they founded an Academy for *Aſtronomy* at *Alexandria*, which furniſhed us with great Men, the chief of whom was *Hipparchus*, who, according to *Pliny*, *undertook a Buſineſs which would have been a great Work to a God to perform, that is, to number the Stars, and leave the Heavens for an Heritage to all that come after.* This Man foretold the Eclipſes of both Sun and Moon for 600 Years; and upon his Obſervations is founded that precious Work of *Ptolemy*, which he call'd his *μεγάλη συντάξις*, or his great Conſtruction; for from them he gathered the Preceſſion of the Equinoxies, and the Theory of the Planets.

WHEN *Egypt* was conquer'd by the *Sarazens*, and *Alexandria* reduc'd under their Juriſdiction, the Conquerors took *Aſtronomy*, with the reſt of the Liberal Arts, under their Protection; and took care that moſt Part of the Books concerning the

Liberal Arts and Sciences ſhould be tranſlated from the *Greek* into their own *Arabian* Language.

THE *Sarazens* paſſing from *Africk* into *Spain*, and having a Commerce with the Weſtern *European* Nations, imparted to them the Science of *Aſtronomy*, which before was almoſt loſt in *Europe*; ſo that about the Year 1230, at the Command of the Emperor *Frederick*, *Ptolemy*'s Almageſt, or his great Syntaxis, was tranſlated from the *Arabick* into *Latin*.

AFTER that Time, *Aſtronomy* receiv'd many Improvements from the Patronage of the greateſt Princes, and the Labours of the moſt celebrated Philoſophers; among whom, in the firſt place is to be nam'd, *Alphonſus* King of *Caſtile*, who is never to be forgotten, on the Account of the *Aſtronomical* Tables call'd after his Name. *Nicolaus Copernicus*, was not only a diligent Obſerver, but alſo a Reſtorer of the ancient *Pythagorean* Syſtem. Prince *William*, *Landgrave* of *Heſs*, who procur'd Quadrants and Sextants much larger than what were formerly us'd, to obſerve the true places of the Stars: This Prince's Obſervations are publiſh'd by *Snellius*. Sir *Henry Savill* was moſt skilful both in *Aſtronomy* and *Geometry*, who is ever to be honour'd, for his Munificence in founding our two Profeſſions of *Aſtronomy* and *Geometry* in the Univerſity of *Oxford*, and endowing them with ample Salaries; upon which Account, and many other Benefits he beſtowed on the Learned World, he will always be had in Remembrance with the greateſt Reſpect. That Noble *Dane Tycho Brahee*, who for his Skill in obſerving was ſuperior to all that went before him; and who for the Furniture of his Obſervatory, exceeded even Princes and Kings: He publiſh'd a Catalogue of 770 fixed Stars, which he had diligently obſerv'd. *John Kepler*, a moſt excellent *Aſtronomer*, by the Help of *Tycho*'s Labours found out the true Syſtem of the World, and the Laws the Celeſtial Bodies obſerve in their Motions, with which he vaſtly improv'd *Aſtronomy*; his excellent Works are well known to the Learned World, and will ever ſhew how much he is to be praiſed. *Galileus*, the *Lyncian* Philoſopher, who firſt applied a Teleſcope to the Heavens, and by its means diſcover'd a great many new ſurprizing *Phænomena*; as the Moon's or Satellits of *Jupiter*, and their Motions; the various Phaſes of *Saturn*; the increaſe and decreaſe of the Light of *Venus*; the Mountainous and uneven Surface of the Moon; the Spots of the Sun; and the Revolution of the Sun about his own Axis; all which were firſt obſerv'd by this great Philoſopher

I ſhould much exceed the Bounds of a Preface, if I ſhould name the reſt of the great Improvers of our Art, with the Praiſes that are due to them; particularly, Mr. *Hevelius*, who has given us a Catalogue of the fixed Stars, much larger than *Tycho*'s, compoſed from his own curious Obſervations. The moſt Illuſtrious Gentlemen, Meſſieurs *Hugens* and *Caſſini*, who firſt ſaw the Satellits of *Saturn*, and diſcover'd his Ring. *Gaſſendus*, *Horrox*, *Bullialdus*, *Ward*, *Ricciolus*, and many other *Aſtronomers* of great Renown. But we have one here, who on Account of his great Merits in *Aſtronomy*, does excell them all, that is, the moſt Eminent and Learned Dr. *Edmund Halley*, Savillian Profeſſor of *Geometry* in this Univerſity, my moſt friendly Collegue; to whoſe Labours *Aſtronomy* owes many, and thoſe not ſmall Improvements: in him there ſhines out together (which I know not if they are to be found in any other Perſon to ſuch a Degree) the greateſt Dexterity in Practical *Aſtronomy*, and a moſt profound and exquiſite Skill in *Geometry*; which will appear by his *Aſtronomical* Tables, which he is ſhortly to publiſh; for they will far excel all others that ever were, or perhaps ever will be publiſhed.

I could name many others of our own Countrymen, who have done much Service towards the Improvement of *Aſtronomy*; but we muſt not paſs over in Silence the Labours of the celebrated Royal Profeſſor, the late Mr. *John Flamſteed*, who with indefatigable Pains, for more than 40 Years, watched the Motions of the Stars, and has given us innumerable Obſervations of the Sun, Moon and Planets, which he made with very large Inſtruments, exactly divided by moſt exquiſite Art, and fitted with Teleſcopial Sights. Whence we are to rely more on the Obſervations he hath made, than on thoſe that went before him, who made their Obſervations with the naked Eye, without the Aſſiſtance of Teleſcopes. The ſaid Mr. *Flamſteed* has likewiſe compoſed the *Britiſh* Catalogue of the fixed Stars, containing about 3000 Stars, which is twice the Number that are in the Catalogue of *Hevelius*; to each of which he has annexed its Longitude, Latitude, right Aſcenſion, and Diſtance from the Pole; together with the Variation of right Aſcenſion and Declination, while the Longitude increaſes a Degree: This Catalogue, together with moſt of his Obſervations, is printed on a fine Paper and Character, at the Expences of the late Prince *George* of *Denmark*; but Mr. *Flamſteed*, before he died, had near finiſhed another Edition of them at his own Expence, which I am told will be ſhortly publiſhed.

Among ſo many Helps and Advantages towards the underſtanding of *Aſtronomy*, there was ſtill wanting an Univerſal and compleat Theory of the Celeſtial Phænomena, explained according to their true Motions and phyſical Cauſes. But this Work has been lately performed, finiſhed and publiſhed by the late Dr. *Gregory*, the great Honour of our Profeſſion, and my Preceptor, whom I ought always to remember with Gratitude; for it is owing to him if I have made any Advances in this Study.

IN the mean time it is to be acknowledged, that this Work does not ſeem to be ſuited to the Capacity of young Beginners; for it contains many Things which require an Inſight into deep *Geometry*, ſo as to be clearly underſtood; which Skill is ſeldom to be met with in young Men, who are for all that capable of learning the Elements of *Aſtronomy*. Beſides the Celeſtial Motions and their Phyſical Cauſes are always jointly explained; which two Things, when they are to be learned by Beginners, diſtracts them too much, and makes the Doctrine difficult. Therefore I thought it more advantageous to the Learner, firſt to explain the Motions, and give an Account of the Phænomena that ariſe from theſe Motions; which, when once underſtood, there will be an eaſy Admiſſion into the Knowledge of Phyſical Cauſes.

FOR which purpoſe, I compoſed the following *Lectures*, which I read in the *Aſtronomical* School at *Oxford*, as my Duty obliged me: In them I have taken ſome Pains, that all the Celeſtial Motions may be clearly explained, and the Reaſons of the Phænomena, which ariſe from thoſe Motions, be given. But particularly of thoſe which are to be underſtood by the help of a few Propoſitions of the Elements of *Geometry*. And therefore I would adviſe our young Beginners, who deſire to learn *Aſtronomy*, that they would place *Euclid*'s Elements before them, when they read theſe *Lectures*, and conſult them when they find any Propoſitions quoted by us. Thoſe we chiefly uſe are but few in Number, ſuch are the 4th. 5th. 8th. 13th. 15th. 27th. 29th. 32d. and 47th of the firſt Element. The 16th. 18th. 20th. 31ſt. 35th. 36th. 37th of the 3d Element: Alſo the 4th. 5th. and 6th of the 6th Element; beſides the Doctrine of Proportion, contained in the 5th Book. It were likewiſe to be wiſhed that the young Student of *Aſtronomy* were skill'd in Plain and Spherical *Trigonometry*. But if there be any, as I believe there are ſome, who deſire to learn *Aſtronomy*, and yet are ignorant of *Trigonometry*; I require of them, that they grant and allow us this *Poſtulate*; Becauſe in every *Triangle*, either Spherical or Plane, there are three Angles and three Sides, of theſe ſix having any three, one of which in a Plane Triangle muſt be a Side, all the reſt may be found. It is *Trigonometry* that teaches us how to perform this, whoſe uſe is apparent in all the Parts of *Aſtronomy*.

THERE are alſo ſome things in our *Aſtronomy*, which require a Knowledge of deep *Geometry*, as when we ſpeak of the Elliptick Theories of the Planets diſcover'd by *Kepler*. But I would not have the Beginners or young Students trouble themſelves with theſe Particulars, ſo they may paſs them over.

I deſire alſo, of them that are unacquainted with *Aſtronomy*, that after they have read the XI and XII *Lectures*, concerning the general Cauſes of Eclipſes, they would leave the reſt of that Doctrine, 'till they are inſtructed in the Spherical Inſtitutions, as they are explained by us in the XX and XXI *Lectures*; and then they may return to the remaining Parts of the Doctrine of Eclipſes, contained in the XIII and XIV *Lectures*.

THEY who underſtand what is here deliver'd, may with much Advantage undertake to read that excellent Work of Dr. *Gregory*'s, and learn the Phyſical Cauſes of the Celeſtial Motions from thence.

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ASTRONOMICAL LECTURES.

* * *

LECTURE I.

Of Viſible and Apparent Motion.

ASTRONOMY being a Science in which are explained the Motions of Bodies that are at an immenſe Diſtance from us, and the Appearances which ariſe from theſe Motions: They who would learn this Science, muſt firſt be informed of the manner how the Motions of diſtant Bodies become viſible, and the Objects of our Senſes.

What Bodies ſeem to be at reſt.

AND firſt it is plain, that ſince the Eye looks upon ſuch Bodies to be at reſt, which keep the ſame viſible Diſtance, the ſame Poſition and Situation, not only in reſpect of other Bodies which we conceive to be at reſt, but alſo in reſpect of the Eye that beholds them; thoſe Bodies can only be perceiv'd to move, which change their Diſtances and Poſitions, in reſpect to other Bodies, or to the Eye of the Spectator.

What in Motion.

Of the Senſe of Seeing.

BUT that we may explain this matter by its proper Principles, and draw it from its Origine, that is from an Explanation of the manner of Viſion: It muſt be known, that the writers of *Opticks* demonſtrate that every Body which is ſeen, has its Image painted in the bottom of the Eye, upon that Coat which is call'd Reticular, or the *Retina*, whoſe Surface is Spherical concave. This Image is made by the Rays of light which flow from the Viſible Object to the Eye, and are therein received and refracted: The Image of each Point is in that place, where the innumerable Rays which come from that Point, and paſſing through the Humours of the Eye, do by Refraction meet on the *Retina*.

Plate I. Fig. 1.

LET AB, a Portion of the Periphery of a Circle, repreſent the outward Surface of the Eye; DG the bottom or reticular Coat, which is formed by the Extremities of the Optick Nerves, and let C be the Center of the Eye: The Image of the Point F will be in the Line FCH, and therefore at H: So alſo the Image of the Point E will be in the Line ECL, at the Point L; for the Rays of Light will, by the pellucid and clear Coats and Humours of the Eye, be ſo refracted, that all thoſe Rays which come from F, and enter the Eye, will change their Direction and turn towards H, where they will meet; and likewiſe all thoſe which come from E, being refracted in the Eye, will converge and meet again at L, where they will form the Image of the Point E; for by ſtriking on the nervous Fibres in theſe Points, they will excite the Senſe of Viſion.

THERE is a fine Experiment which confirms and demonſtrates this Doctrine. For if the Eye of an *Ox*, or any other Creature, juſt after its Death, be taken out of its Head, and the opake and black Coat call'd the *Choroides*, which covers the back Part of the Eye be ſeparated, ſo that the thin and pellucid reticular Coat may appear; if this Eye be turned towards a Window, or any Object that is ſtrongly illuminated, we ſhall ſee with Pleaſure and Admiration, a fine Picture on the *Retina*, exactly Repreſenting the Object in its proper Colours: We ſhall have the ſame Appearance, if inſtead of the Eye we take any Convex-glaſs of a Teleſcope, and turn it towards the Object, and place a white Paper at a due Diſtance behind the Glaſs, we ſhall obſerve upon the Paper, an exact Image of the Object, diſtinctly repreſented with its lively Colours.

How Motion is perceived by our Eyes.

IF therefore the Image H of the Point F remain unmoved on the ſame Point of the *Retina*, the Eye being likewiſe unmoved, the Object F will be at reſt: But if the Point F be carried to E, its Image will thereby ſucceſſively paſs thro' different Parts of the *Retina*, and deſcribing the Space H L, will excite the Senſation of Motion. If the Point F be at a great Diſtance from us, and the Motion be made in a Plain paſſing thro' the Eye, the Spectator will judge of the Magnitude of the Apparent Motion, by the Magnitude of the Angle F C E.

IF in the Line C F there be another Object M, which is likewiſe at a great Diſtance from us, and this Object be carried from M to N, its Motion will Appear to be the ſame with that of the Object F, for the way of both will Appear the ſame, the two Images having the ſame Path, and paſſing thro' the ſame Space in the bottom of the Eye: If the viſible Point M be carried in the Line C F from M to F, ſuch a Motion cannot be perceiv'd by the Spectator, the Image of M remaining unmoved all the while on the *Retina*: And whatever Bodies are moved in Lines that paſs thro' the Center of the Eye, the Motions of ſuch Bodies are not to be Obſerved by our Sight, nor can we any other way diſcern ſuch Motions, but by the increaſe or diminution of the Splendour and viſible Magnitude of the Objects. I ſpeak here of diſtant Objects: For thoſe that are near us, tho' they move in Lines paſſing thro' the Eye, yet we may diſcern their Motions, by the change of Poſition and Situation which they hold in reſpect to other Bodies, whoſe Poſitions and Diſtances are known. Now whatever be the Path of the moveable Point F in the Plain FCE, whither it be in the right Line FE, or in the circular Arch FPE, or in any other curve Line FQE; when it comes to the Line CE, its Apparent Motion will always be ſeen to be the ſame, while the Angle FCE remains the ſame, but when the Angle FCE is increaſed or diminiſhed, the viſible Motion will be in like manner increaſed or diminiſhed, which therefore can be only meaſured by that Angle.

The Meaſures of Angles.

THAT therefore the Apparent Motions of Bodies may be determined, we muſt here ſhew the Method, by which *Geometers* and *Aſtronomers* find out the Meaſures of Angles; which tho' it is commonly known, even to the meaneſt Artiſts, yet that we may omit nothing which will make what is to follow eaſily conceived by Beginners, we will here Explain it in a few Words.

A Degree what? Scruples or Minutes.

EUCLID has demonſtrated that the Angles at the Center of any Circle are proportional to the Arches on which they ſtand, and therefore the Meaſures of Angles will be beſt known from thoſe Peripheries or Arches which ſubtend them: On which Account the *Aſtronomers* divide the whole Periphery of a Circle into 360 Parts which are called Degrees, and they divide each Degree into 60 other Parts which are named Scruples, or Firſt Minutes; each of thoſe Minutes are again divided into 60 Second Scruples or Minutes, and each Second is alſo ſuppoſed to be divided into Thirds, each Third into Fourths; and ſo on.

Plate I. Fig. 2.

BY this means they reckon no more Degrees or Parts in the greateſt Circle than in the leaſt that is, and therefore if the ſame Angle at the Center be ſubtended by two concentrical Arches, they count as many Degrees or Parts in the one as they do in the other; for theſe two Arches have the ſame Proportion to their whole Peripheries. For Example: Let ACB be an Angle, and from the

Center C let there be deſcribed two Arches A B D E, ſubtending the Angle: There are as many Degrees and Minutes contained in the Arch A B, as there are in the Arch D E, altho' the Radius or Semidiameter of the Arch A B were only a Foot long, and the Radius of the other reached the Fixed Stars. It is true indeed, that a Degree in the Arch A B is ſo much leſs than a Degree of the Arch D E, as its Radius C B is leſs than C E or C D: The Angle C is ſaid to be of ſo many Degrees or Minutes as the Arch which ſubtends it contains of ſuch Parts.

The Method of Meaſuring Angles.

Plate I. Fig. 3.

THE Inſtrument by which Angles are obſerved, is a known Portion of the Periphery of a Circle, as a Quadrant, Sextant, or Octant, that is the fourth Part, ſixth Part, or eighth Part of the whole Periphery. If it be a Quadrant, the Inſtrument-Makers divide it into 90 Degrees, 90 being the $\frac{1}{4}$*th* of 360, if a Sextant, it is divided into 60, which is the $\frac{1}{6}$*th* of 360: If an Octant, it contains 45 Degrees, or the $\frac{1}{8}$*th* of 360: They divide again each Degree into Minutes, and each Minute into Seconds, if the Inſtrument be large enough to ſhew ſuch Parts: The Inſtrument-Makers fix to the Side of the Inſtrument Pins or Sights, by which they collineat to the Object, and they faſten likewiſe a Rule moveable about the Center upon the Plain of the Inſtrument, which Rule is likewiſe furniſhed with Sights, with which they obſerve Angles in this manner.

LET A and B be two Objects at a great Diſtance from us: And ſuppoſe the Obſerver at C, who is to meaſure the Angle A C B: Let the Inſtrument be turn'd, 'till the Object A can be ſeen thro' the Sights of the Side C D, and let the Plain of the Inſtrument be ſo moved round the Side C D, and the Rule round the Center, that the Object B may be ſeen thro' the Sights of the Rule: It is manifeſt from what has been ſaid, that the Arch D E will give the Meaſure of the Angle A C B, and that the Arch A B will contain as many Degrees, and Parts, as the Arch D E, which the Rule cuts off from the Inſtrument.

The Horizon.

The Altitude of a Star.

The Pole of the Horizon.

MOREOVER *Aſtronomers* have other Bounds or Marks from which they reckon the *Arcual* diſtances of Stars, and Meaſure them with a like Inſtrument. Theſe are chiefly the *Horizon,* which is formed by a Plane touching the Surface of the Earth where the Spectator ſtands, and is infinitely extended towards the Heavens; which it divides into two Hemiſpheres or Parts ſenſibly equal, and ſeparates the Viſible Heavens from the Inviſible. And if we ſuppoſe a Circle Perpendicular to this Horizon paſſing thro' any Star, the Arch of it comprehended between the Star and the Horizon is called the Altitude or Height of that Star. There is another Mark which is called the Pole of the Horizon, and is that Point which is directly overhead, thro' which a Line Perpendicular to the Horizon will paſs: And it is in this Line all heavy Bodies endeavour to deſcend, and according to which we ſtand upright. By this Method the Sailors at Sea find out the Height of the Sun by the Angle which is formed in the Eye, by Lines coming from the Sun, and from the Horizon. So likewiſe the *Aſtronomers* by Rules and Quadrants made on purpoſe for that uſe, obſerve the Angle which the Rays or Lines that come from the Sun or Stars, make with the Line that is Perpendicular to the Horizon.

INSTEAD of plain Sights we now commonly make uſe of *Teleſcopes,* for by their means diſtant Objects are more certainly and exactly obſerved, than they can be, by our ſimple View. The manner of fitting *Teleſcopes* to Inſtruments, the Method of dividing the Arch, and the Contrivances for managing and moving the Inſtrument for Practice, we leave to the *Mathematical* Inſtrument-Makers to deſcribe.

Plate I. Fig. 4. *The Apparent Diameters of Bodies.*

BY the Meaſure of Angles we likewiſe find the Apparent Diameters of diſtant Bodies: Let AB be a Line which is ſeen by the Eye at C directly oppoſite to it, and ſuppoſe drawn from its Extremities A, B right Lines AC, BC to the Eye, that Line AB is ſaid to appear under the Angle

A C B, which is call'd its Apparent Magnitude, and is ſaid to be ſo many Degrees and Minutes as that Angle obſerved by an Inſtrument contains: After the ſame way the Object D E, ſeen by the Eye F, is ſaid to appear under the Angle D F E, and the Apparent Magnitudes of the Lines A B, D E, are to one another, as the reſpective Angles A C B, D F E.

The apparent Diameters, the nearer we Approach them, grow bigger.

BUT if the Eye come nearer to the Object A B, ſo as to view it but from half the diſtance, that is from G; the Object will be from thence ſeen under twice the Angle it appeared under before: If the Eye come three times nearer, its Apparent Magnitude will be near three times greater, provided the Angles be but ſmall, and exceed not a Degree or two: And the Apparent Diameters of ſuch Objects do nearly increaſe, as the diſtances from which they are view'd are diminiſh'd.

BY this Method, if we know the Apparent Diameters of two Bodies, and the proportion of their diſtances from us, we can know from thence the proportion their true Diameters bear to one another: For if their diſtances be equal, their true Diameters will be as their Apparent: And if their Apparent Diameters are equal, their true Diameters will be proportional to their diſtances. For Example: If the Angle A C B be equal to the Angle D E F, but the diſtance C B triple of the diſtance E F, the Line A B will be triple of the Line D E: But if the diſtance C B be not only triple of the diſtance *c f*, but alſo the Angle A C B be double of the Angle *d f e*, the Object A B will be ſextuple of the Object *d e*: For if we ſuppoſe C M equal to *d f* and an Object M N, becauſe the Angle M C N; or A C B is double of the Angle *d f e*, M N will be double of *d e*; but becauſe C B is triple of C M or *d f*, A B will be triple of M N, and conſequently it will be ſix times bigger than *d c*. Hence if the Apparent Diameters of the Sun and Moon be equal, let the Sun be 100 times further from us than the Moon, the Sun muſt needs be 100 times in Diameter bigger than the Moon: We ſhall afterwards demonſtrate that the Sun's

Plate I. Fig. 4, 5.

Diſtance from us is above 100 times greater than that of the *Moon*

IF we know the Apparent Diameter of any Body, we can from thence, exactly know by the help of *Trigonometrical* Tables, what Proportion the Diſtance of that Body bears to its true Diameter. For ſuppoſe the Object DE to be ſeen by the Eye at F under the Angle DFE. For Example of one Degree; then the Diſtance FE will be to DE the Diameter of the Object, as the Radius of a Circle is to the Tangent of the Angle DFE; that is ſuppoſing DFE one Degree, as 10000 is to 174,5. The Sun appearing under an Angle of about half a Degree, or 30 Minutes, its Diſtance will be to its own Diameter as 10000 to 87: Hence we are certain that the Sun's Diſtance from us, is nearly equal to 115 of its own Diameters. And if an Eye were placed in the Sun, to obſerve the Angle under which the Diameter of the Earth appeared from thence, we then ſhould be able to tell exactly the Diſtance of the Sun from us, in Diameters of the Earth, or in Miles.

The Advantages of Teleſcopes.

SINCE, as we have ſaid, the Apparent Diameters of Bodies grow bigger the nearer we come to them, and that they are increaſed almoſt in the ſame Proportion that the Eye approaches them; (for Example: If any Man were ten times nearer to the Moon than we are, and did there obſerve it, he would ſee the Moon ten times bigger in its Diameter and clearer than we do; in Diameter I ſay, for the Surface would Appear 100 times larger than it does to us.) If here on Earth we ſhould take a Teleſcope which only encreaſes the Diameter ten times, and look to the Moon with it, the Moon will have the ſame Appearance ſeen with ſuch a Teleſcope, as would appear to a Spectator ten times nearer it than we are. But if we ſhould uſe Teleſcopes (and ſuch there are) which Magnifie the Diameters of Objects 100 or 200 times, they will ſhow the Moon in the ſame manner, figure and bigneſs, as it would appear in, at a Diſtance 100 or 200 times leſs than ours.

Hence we can perceive with our Eyes with what Face, and how large the *Moon* would ſhow it ſelf, at the Diſtance of three Diameters of the Earth: As likewiſe we can diſcern how it would appear if we approached it much nearer, and view it only at the Diſtance of 1000 Miles; for from thence we ſhould be able to diſcover in it vaſt Ridges of Mountains, deep Caverns, many Vales, and large open Fields. By the means of Teleſcopes we ſtill aſcend higher in the Heavens, and we can approach the Planets, Comets and fix Stars ſo near, that of ſuch immenſe Diſtances, there remains only the hundredth, or two hundredth Part to have the whole Journey finiſhed: And from thence we can behold the Converſions of the Planets about their proper *Axes*; the Moons of *Jupiter* and *Saturn*, their Eclipſes; the Belts of *Jupiter*, the wonderful Ring of *Saturn*, and all the various Appearances and Shapes it takes. We could not paſs over, without taking Notice in this Place, theſe advantages of the Teleſcope, ſince it is the chief Inſtrument by which we Obſerve the Magnitude of the Heavenly Bodies, and their Apparent Motions.

How the Motions of far diſtant Bodys which are in themſelves equal, may appear unequal.

SINCE the Motions of diſtant Bodies are no other ways to be known, but by the change of the Angle which is at the Eye that obſerves them; it will eaſily appear from thence, that tho' Bodies move equally and regularly, deſcribing equal Spaces in equal Times, their Motions notwithſtanding may ſeem to be very unequal and irregular. This will be beſt underſtood by an Example.

Plate I. Fig. 6.

SUPPOSE a Body to be revolv'd in the Periphery of a Circle A B D E F G Q, and to move thro' equal Arches A B, B D, D E, E F, in equal Times; and let the Eye be in the Plane of the ſame Circle, but at a Diſtance from it, viewing the Motion of the Body from O: When the Body goes from A to B, its Apparent Motion is meaſur'd by the Angle A O B, or the Arch H L, which it will ſeem to deſcribe; but in an equal Time, while it moves thro' the Arch B D, its Apparent Motion is determined by the Angle B O D, or the Arch L M, which is much leſs than the former Arch H L, and the Body when it arrives at D will be ſeen at the Point M of the Periphery N L M: But it takes the ſame time to deſcribe D E which is equal to A B, or B D, and when it arrives at E it is ſtill ſeen at the Point M; ſo that all the time it is moving thro' the Arch D E, it appeares almoſt immoveable, and as it were to ſtand ſtill. While the Body is continually going forward in its proper Orbit, and deſcribing the Arch E F, when it comes to F the Eye in O will ſee it in L, and it will appear to have gone backwards in the Arch M L. So alſo while it moves from F to G, at its arrival at G, it will be ſeen at H in the very ſame Place it appeared in when it was in A. So likewiſe while it paſſes from G thro' I to Q, the Spectator's Eye at O will obſerve it as if it had deſcrib'd the Arch H K N. And tho' it is ſtill going on it is Orbit, while it runs thro' the Arch Q P, the Spectator will obſerve it all that time near the Point N, in a *Stationary* State. After its paſſing by P, and going to A, it will appear to change again its Courſe, and deſcribe the Arch N K H L M with very unequal Motions.

Optical Inequality.

THIS Inequality of Motion is call'd by *Aſtronomers* the *Optical Inequality*: Becauſe it is not really in the Bodies moved, but only Apparent to the Eye which perceives it, ariſing from the Poſition of the Spectator: For the Body all the time moves uniformly forward, and if the Eye were in the Center, it would ſee the Motion always perfectly regularly performed.

Plate I. Fig. 7. *If the Eye be placed within the Circle, the Motion that is equal, may appear Unequal, but the Body can never be ſeen to go backward or to change its Courſe.*

IF the Eye were placed in any Point, as O within the Orbit of the Body, but not in the Center, and there the Spectator remained immoveable, he would ſtill obſerve the Motions to be unequal, altho' the Body moved never ſo regularly; and when at the greateſt diſtance from him, as at A, it would appear to be ſloweſt; when it comes neareſt, it would ſeem to move quickeſt. This is plain, for the Arches A B and C D being equal, they will be deſcribed in equal times. But the Angle DOC being greater than AOB, the Motion in D will appear ſwifter than that at A. But in this Caſe the Body will never appear to ſtand, or to go backwards, but always forward: And therefore when a Spectator placed within the Orbit of another Body, and viewing its Motion, perceives it ſometimes to go forward, then to ſtand ſtill, and afterwards to go backward, we may from thence conclude that the place of the Spectator is likewiſe moved.

LECTURE II.

Of the Apparent Motion which ariſes from the Motion of the Spectator, or Obſerver.

HITHERTO we have ſuppoſed the Spectator to have remained immoveable all the time of the obſervation: But if the Place of the Obſerver be likewiſe moveable, then there will be very different Appearances, and the Eye will perceive thoſe Bodies to be at reſt which may have really a very quick Motion, and other Bodies may ſeem to be in Motion, which remain really at reſt: And not only theſe appearances may be ſeen, but the Motion of Bodies may appear to be directly contrary to what they truly are, and Bodies which are really going *Eaſtward* may appear to move towards the *Weſt*. All which will be moſt eaſily declared and made plain from the appearances obſerved by them who Sail in a Ship,

They who Sail in a Ship, perceive not the Motion of the Ship.

SUPPOSE a Ship carried by the Winds with a ſwift but uniform Motion; the Paſſengers can neither perceive the Motion in the Ship, nor of any thing in it that keeps the ſame relative place in the Ship: For ſince the Veſſel and all its Parts retain the ſame Situation and Poſition in reſpect of the Eye, their Images painted on the *Retina* will always abide in the ſame Place, and therefore they muſt appear unmoved. Hence it is, that tho' every Thing in the Ship goes as faſt forward as the Ship it ſelf does; yet ſuch Motions cannot be perceived by a Spectator that ſits in the ſame relative Place, and who has the ſame common Motion with the Ship. But when the Spectator turns his Eyes towards the Shoar, or upon Objects which are without the Ship, they will ſeem to be moved; for while the Ship goes forward it carries along with it the Eye of the Spectator, by which Motion of the Eye the Poſition of external Objects in reſpect of its ſelf will be changed, and their Images will ſucceſſively occupy different Places on the *Retina*, and therefore Objects without the Ship which are really at reſt will ſeem to be moved, whereas thoſe that are within the Ship, and really in Motion, will appear to be at reſt.

But external Objects without the Ship will ſeem to move.

IF while the Ship is moving very faſt forward a Ball of Lead, or any other heavy Metal, were let fall from the Topmaſt, the Paſſengers in the Ship will obſerve the Ball to fall perpendicularly downwards, and it will fall upon the Deck juſt by the Foot of the Maſt, after the ſame manner as it would fall were the Ship at reſt. But notwithſtanding this, the true Motion of the Ball is not in the Perpendicular, but in an Oblique Line, in which it deſcends; and a Spectator in another Ship which is at Anchor, will eaſily obſerve this Obliquity and Curvity of its way while it falls thro' the Air. The reaſon of this appearance is eaſily ſhewed: For according to the firſt and principal Law of *Natural Philoſophy*, a Body once put into Motion, endeavours to retain that Motion, and to continue moving in the ſame direction. Now the Ball while it was held at the Topmaſt went forward with the Ship, and had its Motion communicated to

The Motion of a Ball falling down in a Ship.

to it; and therefore after it is left to fall, it will retain the ſame Force to go forward as it did before; and at the ſame time, its Weight carrying it downwards, it will both go forward and deſcend: For the two Forces, one communicated by the Ship, and the other from Gravity, will not hinder or diminiſh one another, they not being contrary. It will therefore be moved as faſt forward, and as much downward as it would be, did the two Forces act upon it ſeparately at different times. By theſe two Forces acting together, the Rectitude of its way is only hindered, which it would have, did the Perpendicular and the *Horizontal* Forces act ſeparately; and the real way of the Ball thro' the Air is a curve Line, exactly like that which a Body takes when it is thrown according to an *Horizontal* direction: And in ſuch a Line it will be obſerved to move, by a Spectator placed near it in another Ship which is at reſt. Beſides, ſince the Ball and Maſt are both moved forward with the ſame Velocity, they will always remain at the ſame Diſtance from each other, and therefore the Ball will touch the Deck juſt by the Foot of the Maſt. Moreover the Motion of the Ball forward is common to the Ship, and all its Parts, as likewiſe to the Paſſengers that are relatively at reſt in the Ship: But we have before ſhewed, that the common Motion could not be obſerved by the Paſſengers in the Ship, and therefore it cannot be perceived neither while the Ball is falling. Wherefore the only Motion that can be ſeen, will be that which is impreſt upon it by its Gravity, which is peculiar to the Ball, and by which it deſcends. And therefore the Paſſengers will ſee the Ball deſcending only in a Perpendicular Line. Experiments have been often made, which demonſtrate that all we have ſaid is exactly true.

The Motion of a Ball thrown within the Ship.

IF any Perſon ſitting at the Ship's Head, ſhould throw a Ball towards the Stern with the ſame Velocity that the Ship goes forward, that ball would neither go forward nor backward; and if there were no Gravity it would remain immoveable:

But becauſe Gravity Acts upon it, it will really deſcend in a Perpendicular Line, and a Spectator in a Ship at Anchor would obſerve it deſcending in a Right Line. For the force impreſt upon it when it is thrown, will only deſtroy the firſt force communicated to it from the Ship, to which the Projectile force is contrary and equal. But for all this, the Paſſengers will not perceive this Perpendicular and direct Motion, but they will ſee the Ball go towards the Stern with the ſame force, as it really would have done, had the Ship been at reſt, and the Ball been thrown with the ſame force to the Stern.

BUT if the Velocity with which the Ball is thrown toward the Stern ſhould be leſs than that of the Ship, the real Motion of the Globe will be forward, in the ſame direction in which the Ship goes, but ſlower than it; for the whole Motion communicated by the Ship will not be deſtroy'd, and there will ſtill remain a Part of its former Motion, by which it will be carryed forward, tho' not ſo faſt as before. But the Paſſengers will perceive no ſuch Motion, but they will obſerve the Ball to to be moved in a Line directly contrary to its real Motion, with that very Velocity that it would have, were it thrown when the Ship is at reſt: Hence it is plain that Bodies may appear to have a Motion directly contrary to their real and abſolute Motion.

An Objection.

BUT ſome may Object, that the Ball thus thrown, will really hit the Stern of the Ship, and impreſs on it a conſiderable Blow, which it could not do, had it not a Motion towards the Stern. But this difficulty is eaſily removed; for tho' they that are within the Ship ſee the Ball go and hit the Stern, a Spectator without, who is not in Motion, will obſerve that the Ball does not come upon the Stern and give it a Stroak, but that the Stern ruſhes upon the Ball, and acts upon it with all its force: And the force of the ſtroak which each Body receives is the ſame as if the Ship had been at reſt, and the Ball had fallen upon it with the ſame Velocity that the Stern does really come againſt the Ball; for it is known from the Laws of Motion, that if there be any two Bodies A and B equal or unequal, the force of the Stroak will be the ſame, whither B with a certain Degree of Velocity comes upon A which is at reſt; or if B ſhall be at reſt, and A with the ſame Velocity ruſhes upon B; or if both Bodies move the ſame way, but A moving faſter by its greater Velocity gives B an impulſe, the force of the Stroak will be the ſame as if B were at reſt, and A came upon it with the difference of their Velocities, that is by the exceſs wherewith the Velocity of A is greater than that of B: Or Laſtly, if A and B have contrary Motions, and hit one againſt the other, the greatneſs of the Stroak will be the ſame as if one of them ſtood ſtill, and the other come againſt it with the ſum of their Velocities. In one Word, whatever the real Velocities of the Bodies may be, ſo long as their relative Velocities, or the Velocities by which they approach each other remain the ſame, the force of the Stroak will likewiſe remain the ſame. Hence it is, that in a Ship, however ſwiftly it may Sail, all our Apparent Motions, and the Motions of every thing in the Ship, do all appear to be the ſame that they would, were the Ship at reſt: And it is obſervable that *Flies* and other *Inſects* keep the ſame Motion in regard to one another, whither the Ship is at reſt, or Sails uniformly forward with any degree of Velocity, let it be never ſo great. And it is Univerſally true, that all Bodies that are ſhut up in any one Place, preſerve the ſame Motions in regard of one another, and all appearances will be the ſame, whither the Place remains unmoveable, or has a direct uniform Motion forward.

Plate I. Fig. 8.

I have brought theſe Examples that you may perceive how wide the Differences may be between real and Apparent Motions, and how hard it is to judge of real Motions, by thoſe that are ſeen.

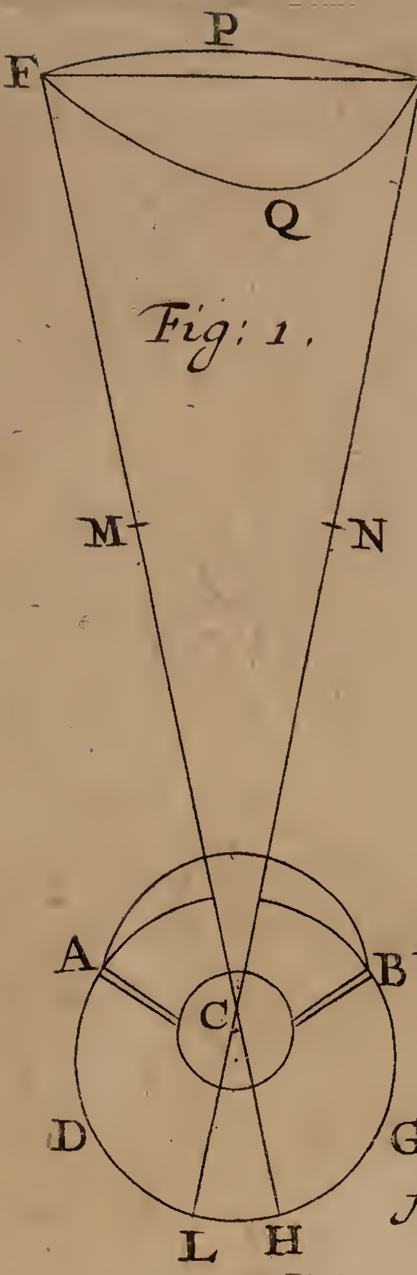
BY this it is evident, that if a Spectator were placed in *Jupiter*, or *Saturn*, or in any other of the *Planets*, he can never be made ſenſible of the Motion of his own Habitation, no more than they who Sail in a Ship can perceive the uniform motion of the Ship. Paſſengers who Sail in Ships may indeed be very ſenſible of the frequent Toſſings and ſudden Shocks the Ship receives from the Waves and Wind, which they find exceedingly troubleſome to them. But the *Planets* which compoſe a Celeſtial Fleet, are not liable to any Storm, they without any Diſturbance or Commotion circulate in their Orbits, and Sail as it were in a moſt Pacifick Ocean, which is continually Calm and Serene.

LECTURE III.

Of the Syſtem of the World.

WE have ſhewed that according to the different Situation and Motions of the Spectator, the Appearances of Things will be very various and different. That we may have a more Diſtinct knowledge of the Fabrick of the *World*, and that the admirable Beauty of the Univerſe, and the harmonious Motions of the Bodies therein contained may be more eaſily underſtood, it will be requiſite that that Divine and Immenſe Fabrick ſhould not be obſerved from one Point or Corner only: But as in Viewing of large Palaces, we take the different Proſpects they afford from ſeveral Places; ſo here to have a true and juſt Notion of the World, we muſt ſuppoſe it to be obſerved in dif-

Plate I.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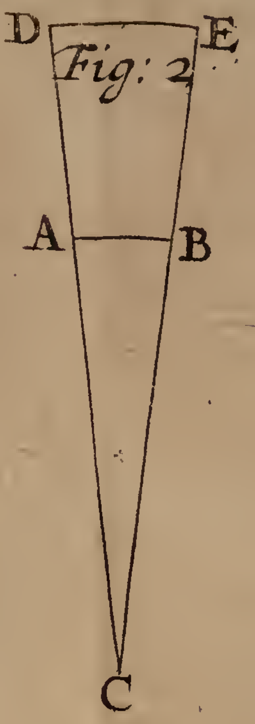
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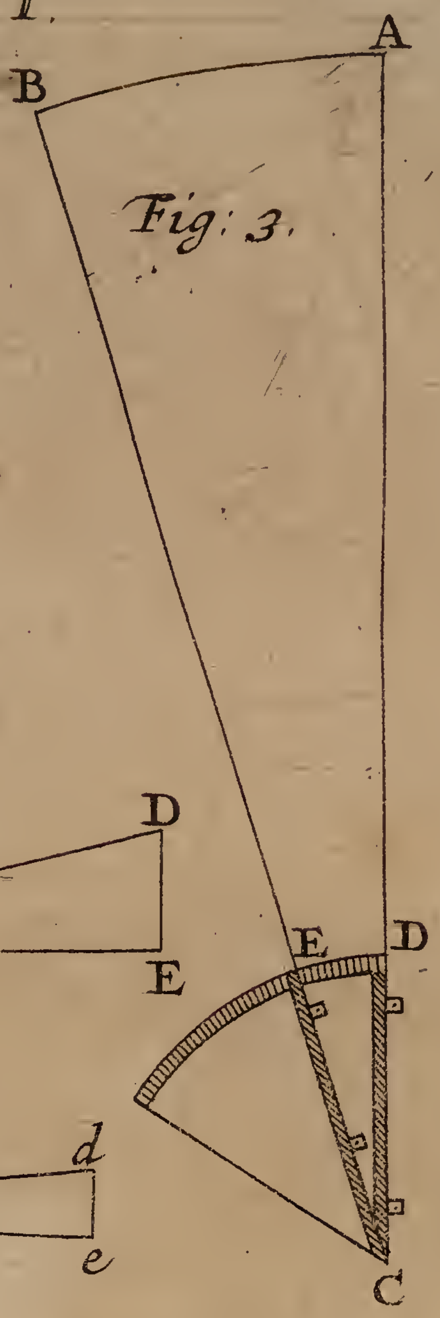
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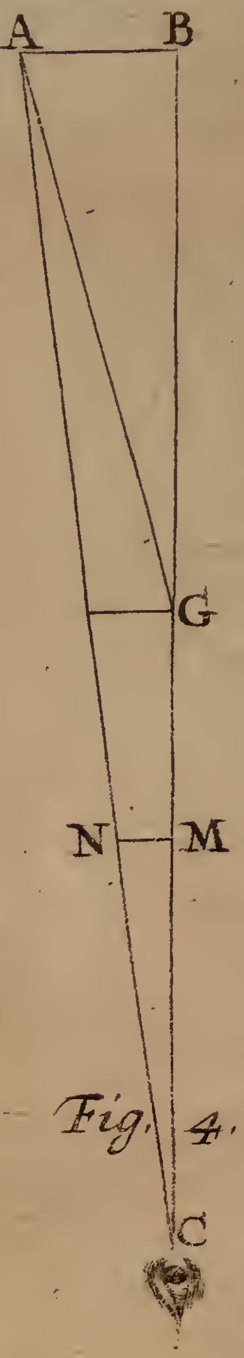
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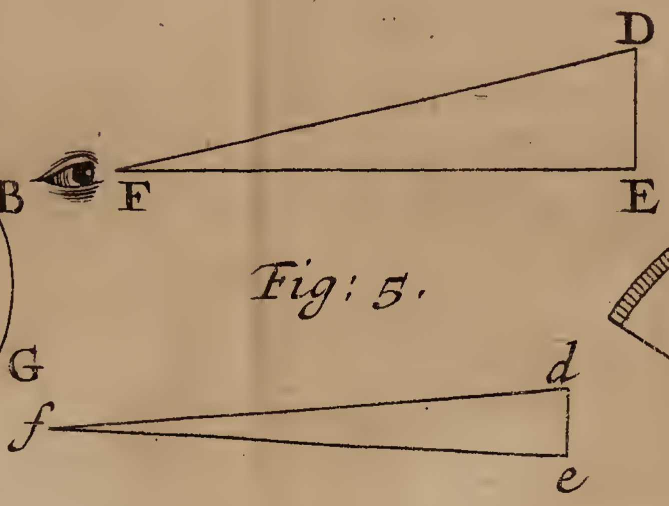
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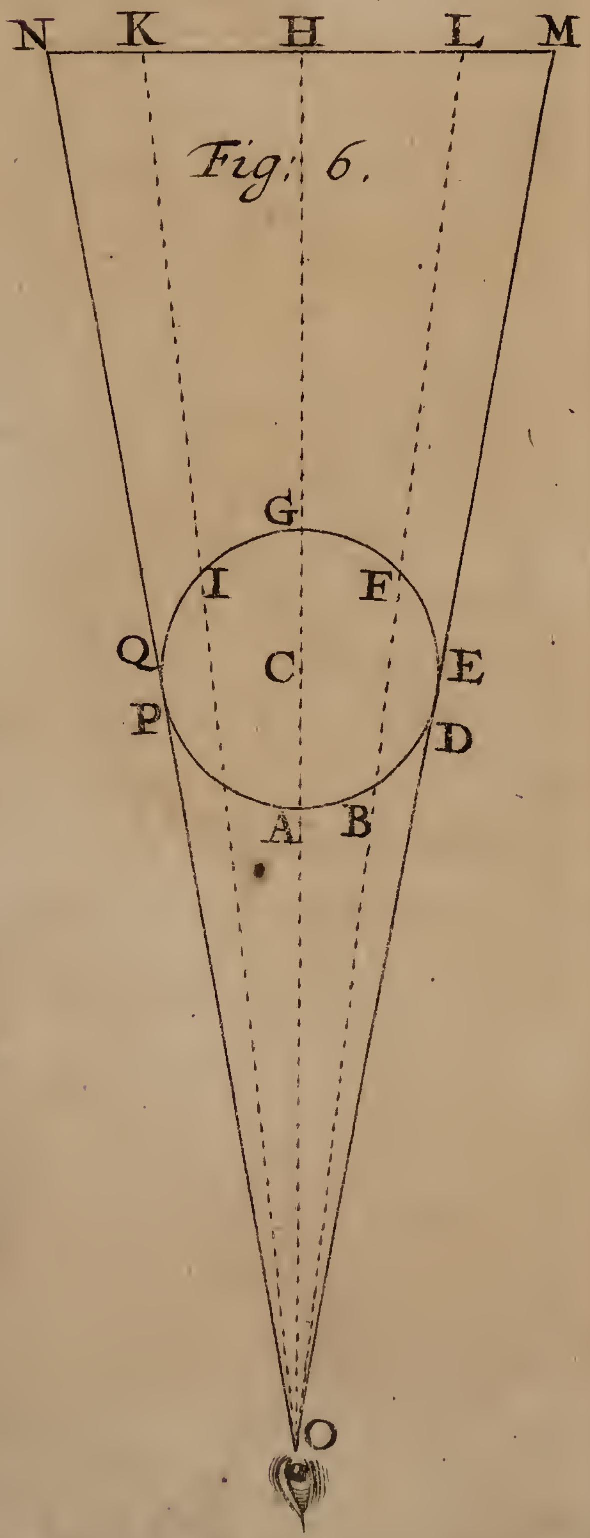
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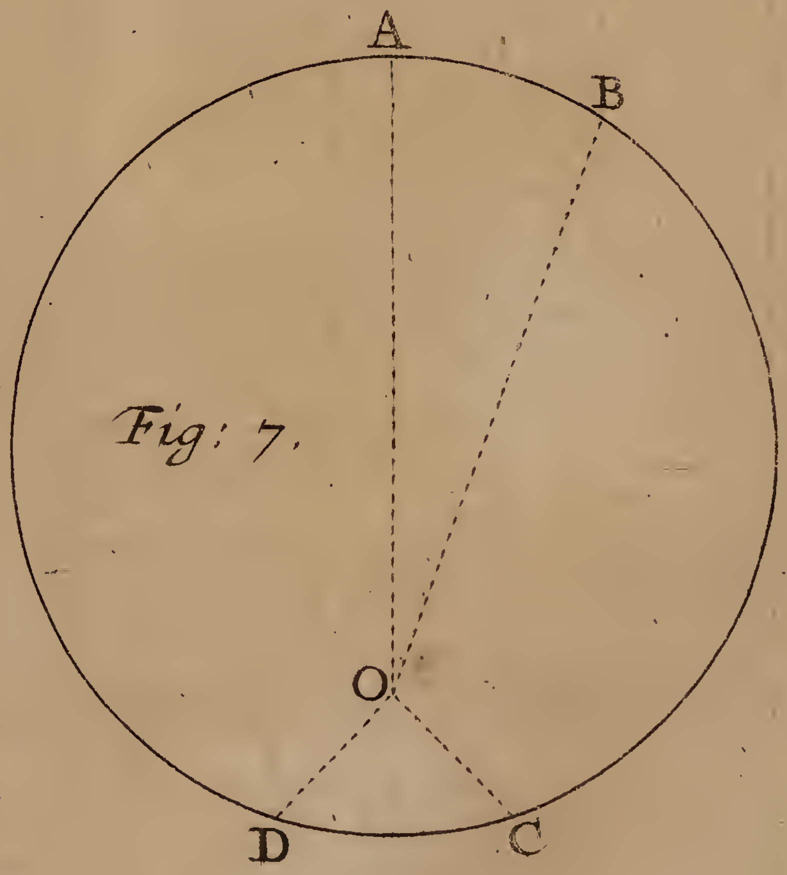
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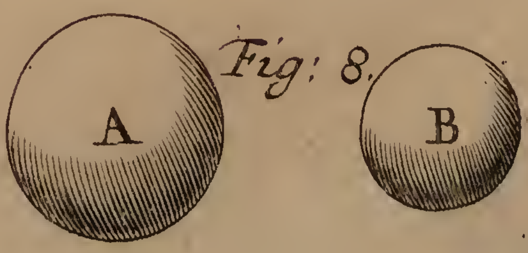


Fig: 8.

different Situations and Diſtances, that by contemplating the various Proſpects it gives us, and comparing them together, we may obtain at laſt a diſtinct Knowlege of this Immenſe Palace of *God Almighty*, and have an *Idea* or Image of it impreſſed on our Minds, which is worthy of its Infinitely wiſe *Architect*.

FOR to underſtand therefore the Heavenly Bodies, their Motions, and Appearances, which are called *Phænomena*, we muſt feign our ſelves not to be Inhabitants of this *Earth*, and fixed to one Habitation, but ſuppoſe we have the Power of Travelling every where, thro' the Immenſe Regions of indefinite Space; and therefore we will ſometimes take Poſſeſſion of ſome immoveable Place, from thence we will transfer our ſelves to the *Sun*, to obſerve the Regularity and Harmony of the Motions which are to be ſeen from thence, afterwards we will take a Journey to ſome other of the *Planets*, that we may from them obſerve the Apparent Motions of the Heavens; nor will we confine our ſelves within this *Planetary Syſtem*, but we will yet aſcend much higher in the Heavens, and view the World from a *Comet* or fix'd *Star*.

We may imagine our ſelves to have a free Courſe or Paſſage thro' all the Parts of the Univerſe, and of paſſing from one Star to another.

We, tho' from Heaven remote, to Heaven will move
With ſtrength of Mind, and tread the Abyſs above:
And Penetrate, with an Interior Light,
Thoſe upper Depths, which Nature hid from ſight.
Pleas'd we will be to walk along the Sphere
Of ſhining Stars, and travel with the Year.
To leave this heavy Earth, and Scale the Height
Of Atlas, *who ſupports the Heavenly weight:*
To look from upper Light, and thence Survey
Miſtaken Mortals wand'ring from the way.

OVID's *Metamorphoſis*, Book XV.

NOW, tho' our Bodies by reaſon of their Gravity towards the Earth, are detained as it were Priſoners in this earthly Manſion; yet nothing hinders, but that with our Mind and Imagination, we may wander thro' all the Heavenly Regions, and from them Contemplate with the Eyes of our Reaſon, the whole Syſtem of *Nature*. Nor do I ſee how this liberty of Imagination can be denyed us, which was always allowed to the *Aſtronomers* of all Ages; for they to obſerve the equal Motions of the Heavens, thruſt the Spectator down to the Center of the Earth, and ſuppoſed that the Heavens were viewed from thence, as from the Center of a Cryſtal *Globe*. An *Aſtronomer* thinks it no great Conceſſion or *Poſtulatum*, that he can draw a Line from the *Sun* to the Center of the Earth; and from thence again to any *Planet* or Star. He divides the Heavens with his Circles, and marks out the ways of the Planets; and indeed without ſuch a Licenſe he could never have brought *Aſtronomy* to any degree of Perfection.

AS therefore it was a Cuſtom among the *Aſtronomers*, to place the Eye in the Center of the Earth, to view from thence the Apparent diurnal Revolution of the Heavens; which would from thence be ſeen an equable Motion. We will on the contrary, carry the Spectator to ſome immoveable place in the Heavens; that the real and abſolute Motions may be obſerved from thence as much as they can be, equable and uniform. For the *Aſtronomers* of all Sects do agree, that the Motions of the Planets are in themſelves ſimple, regular and uniform: But when the Heavens are viewed from the Surface of the Earth, or even from its Center, the Planets ſeem to be carried by very unequal Motions, and not to obſerve any regular Courſe; and therefore we may certainly conclude, that our Earth is not placed in the Center of their Motions. He therefore that would obſerve the real and proper Motions of theſe celeſtial Globes, muſt firſt place him-

The Planets ſeen from the Earth, have unequal and irregular Motions.

himſelf in the Center of the Sun, or in ſome Point or Space not far diſtant from it; and then let him conſider what will be the Appearances or *Phænomena* he will behold from thence.

The Spectator is always in the Center of his own view.

AND firſt it is to be noted, that wherever the Spectator reſides, he will ſtill be in the Center of his own view; for in an indefinite Space, where there is nothing to bound our Proſpect, all Objects that are at a great Diſtance from us, tho' they be at immenſe Diſtances from one another, yet if they appear in the ſame right Line which paſſes thro' the Eye, will be ſeen at the ſame Point of Space; and all Bodies will appear equally remote, when their Diſtances from us become ſo great, that the Eye cannot eſtimate or judge of them: And conſequently the Spectator will look upon them all as placed in the Surface of a Sphere, which has the Eye for its Center, and whoſe Surface is at an immenſe Diſtance, in which Surface, all the heavenly Bodies will ſeem to perform their Motions. Thus tho' the *Moon* be many Millions of Miles nearer to us than the *Sun*, and he again much nearer than the fixed *Stars*, yet all appear as placed in the ſame concave Surface of the Heavens: And even the Clouds which are but a few Miles above us, would be judged to be as far diſtant as the *Moon* and *Sun*, if they did not ſometimes cover them, and obſcure their Light. In whatever place therefore the Spectator reſides, whether it be in the *Earth*, or the *Sun*, or in *Saturn* the furthermoſt of the *Planets*, or even in a fixed *Star*, that place will be looked upon by its Inhabitants as the middle Point of the Univerſe, and the Center of the World; ſince it is the Center of that ſpherical Surface in which all diſtant Bodies ſeem to be placed.

The Proſpect of the World from the Center of the Sun.

A Spectator therefore living in the *Sun*, when he looks towards the Heavens, will obſerve its Surface to be ſpherical concave, and concentrical to his Eye; in which Surface he will obſerve an innumerable multitude of *Stars*, which we call *Fixed*, every where diſperſed throughout the whole Heavens, which like ſo many gilded Studs, with a bright Luſtre adorn the Firmament. Theſe *Stars* we call *Fixed*, becauſe as ſeen from the *Earth*, they preſerve the ſame immutable Poſitions and Diſtances from each other; and ſo from the *Sun* likewiſe, they will appear always to retain the ſame Situations in reſpect of one another, nearly as they are obſerved to have when ſeen from the Earth. For their Diſtance either from the Earth or Sun is ſo great, that the little change of place (however great it be when compared to our common Meaſures) which is made by bringing a Spectator from the Earth to the Sun, will ſcarcely make any change in the viſible Situation of the Stars. Now tho' the fixed Stars ſeen from the Earth do always preſerve the ſame Diſtances, Poſitions and Situations in reſpect of one another, yet in reſpect of the Eye we obſerve them to change their Poſitions, and ſometimes they ſeem to mount higher in the Heavens, and to come more perpendicularly over us; then they deſcend again and appear to turn round in Circles, ſome in greater, ſome in leſs, about an Axis which is the Axis of the Earth: And this Circumvolution of theirs is every Night to be obſerved from the Earth; but whoever would view them from the Center of the Sun, would perceive them abſolutely immoveable, and always abiding in the ſame place of the Firmament. And this Appearance will be the ſame, whither the Stars do really reſt in the ſame place; or whither the Heavens, in which the Stars are placed together with the Sun, revolved round the Axis of the Earth: For if there were really any ſuch revolution of the Heavens, a Spectator in the Sun would have that Motion in common with the Stars, and therefore he could be no more made ſenſible of it, than a Paſſenger in a Ship can obſerve by his Senſes the Courſe and Motion of the Ship.

The immenſe Diſtance of the fixed Stars from the Sun.

The Stars change their Poſition in reſpect of the Spectator.

BESIDES the innumerable Stars at reſt, there are Six other ſhining Globes to be obſerved, which perform their circulations round the Sun, in very different Periods of Time: And therefore they muſt have conſtantly variable Poſitions, and be always changing their Diſtances from one another, as well as from the quieſcent Stars. Theſe Globes or Stars are called *Planets,* which ſignifies *Wanderers,* and one of them is the *Earth,* the place of our Abode. And even tho' we ſhould ſuppoſe the Earth to be at reſt, and that the Sun did really move round it in the Space of a Year, yet a Spectator in the Sun would obſerve that the Earth turned round about him; and would ſee it deſcribe the ſame Circle in the Heavens, that we in the Earth obſerve the Sun to perform his Courſe in; as we ſhall afterwards demonſtrate.

The ſix Planets, or Wanderers.

The Planets turn round the Sun *from* Weſt *to* Eaſt.

THE Names and Characters, or Marks for the Planets are *Saturn* ♄, *Jupiter* ♃, *Mars* ♂, the *Earth* ⊕, *Venus* ♀, *Mercury* ☿. Theſe Characters were Invented by the *Aſtronomers* as Abbreviations in writing. The Planets do all turn the ſame way as the Sun, from the *Weſt* to the *Eaſt,* in Orbits which lye in Planes, which are not much inclined to one another, but nearly coinciding: So that the Planes of theſe Orbits in the Heavens, being little inclined to one another, make Angles with that Circle in which the Earth is ſeen to turn round the Sun, but of a very few Degrees. As all Planes that are not Parallel, cut one another in right Lines; ſo the Planes of the Orbits in which the Planets move, cut one another in Lines that paſs thro' the Sun's Center; and therefore a Spectator there placed will be in the Plane of each Orbit, and will obſerve that the Planets moving in the concave Surface of the Heavens, perform their Motions in great Circles, which divide the Heavens into equal Portions. Now the Eye being in this Situation, in the Planes of all the Planets Orbits, can never by that means judge of their different Diſtances from the Sun; for from thence they will all ſeem to be at the ſame Diſtance from him: And therefore to obſerve their different Diſtances, Lect. III. as well as Periods, it will be neceſſary that our Spectator ſhould remove from the Sun, and riſe above the Planes of all the Orbits, in a Line Perpendicular to the Plane of the Earth's Orbit; and, for Example's ſake: Let us Suppoſe him to riſe ſo high, as that his Diſtance from the Sun may equal the Earth's Diſtance from it, and let him there make his *Aſtronomical* Obſervatory: From thence he will not only obſerve the ſame fixed Stars in the ſame Poſition as before, but he will ſee both Sun and Planets in the Heavens: The Sun indeed will appear like the fixed Stars, immoveable; but the Planets will be ſeen to turn round in leſſer Circles about him, at very different Diſtances, and in different Periods; They who finiſh their Circuits ſooneſt are ſeen neareſt to the Sun, and the Circles they move in are the leaſt; they who take a longer time in revolving deſcribe larger Circles, and are further removed from the Sun; and the order of the Planets will be ſuch as is repreſented in Figure 1 *Plate* II. Where the Sun remains unmoved in the Center of all the Orbits; round about him ſix Planets make their Revolutions, *viz.* *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*, all from the *Weſt* to the *Eaſt*, according to the order of the Letters A B C D. *Mercury* is next the *Sun*, and finiſhes his Courſe in three Months: *Venus* in an Orbit ſomewhat larger, performs her Period in eight Months: Beyond the Orb of *Venus*, is that of the *Earth*, which revolves round the *Sun* in the ſpace of a Year: *Mars* takes two Years to compleat his Circulation: And *Jupiter* at a much greater Diſtance, does not finiſh his Revolution 'till after twelve Years: The furthermoſt and ſloweſt of all is *Saturn*, whoſe Orbit includes all the others, and requires not much leſs than 30 Years to compleat his Courſe.

The order of the Planets.

Plate II. Fig. 1.

The Antient Pythagorean *Syſtem.*

THIS was the Antient Syſtem of the World, which was at firſt introduced into *Greece* by the Great *Pythagoras* and his Diſciples, who had learned it from the Wiſe Men of the *Eaſt*, to whom, as to an Univerſity they then all reſorted for Inſtruction. 'Tis true, the other Apparent Syſtem, which ſuppoſes the Earth immoveable, and the Heavens to revolve about it, was received among the Vulgar and Illiterate part of Mankind; yet the Philoſophers retained the true Syſtem, 'till *Ariſtotle* and the Philoſophers that came after him, degenerating from their Predeceſſors, and not being acquainted with true Philoſophy, embraced the Common Syſtem of the Vulgar: So that the Antient Syſtem was forgot, and not minded 'till the time of *Nicolaus Copernicus*, who again brought it to life and retrieved it from Oblivion; and eſtabliſhed it by ſolid Arguments and Reaſons: Whence this Syſtem is now called the *Copernican Syſtem.* After the Invention of Teleſcopes, the Secundary Planets, with many new and unthought of Appearances, were obſerved in the Heavens by the *Aſtronomers*, which did wonderfully enlarge the Antient Syſtem, and confirm'd it with invincible Demonſtrations.

The Planets are opake ſpherical Bodies.

IF a Spectator ſhould with a Teleſcope more nearly view the Planets, he will ſoon find that they are ſpherical Bodies, and opake, like our Earth; having no proper Light of their own, but that they ſhine with the borrowed light of the Sun; for that ſide of them which is turned towards the Sun is always illuminated, and it is by the reflected Light of the Sun, that they become viſible: But the ſide oppoſite to the Sun, which the borrowed Rays cannot reach, remains dark and obſcure. And beſides this, as all opake Bodies do, the Planets caſt a Shadow behind them, which is always oppoſite to the Sun. The Line in the Planets Body which diſtinguiſhes the lucid part from the obſcure, is ſometimes right, ſometimes crooked; and it is ſometimes convex towards the Splendid part and Concave on the obſcure; ſometimes on the contrary, it appears Convex towards the obſcure Side and Concave towards the ſhining Face of the Planet, according to the different Situation of the Eye in reſpect of the Planet, and of the Sun which illuſtrates the Planet; which different Poſition is likewiſe the cauſe why ſometimes we ſee a greater, ſometimes a leſſer Portion of the illuminated Face; as it ought to be in ſpherical opake Bodies which are expoſed to the bright light of the Sun.

The Secundary Planets.

THREE of the Planets, *viz.* The *Earth*, *Jupiter* and *Saturn*, have other leſſer Planets which continually accompany them, theſe are called Secundary Planets, Moons or Concomitants; for they conſtantly keep cloſe to their reſpective Primaries, and always attend upon them in their Circulation round the Sun; and in the mean time each of them performs his proper Revolution round his proper Primary. The *Earth* indeed has only the *Moon* to keep her company, who never forſakes her in her Annual Courſe round the *Sun*, and while ſhe attends upon us, ſhe performs proper Circulations of her own round the *Earth*, in the ſpace of a Month.

The Earth is accompaned by the Moon.

THAT the *Moon* appears ſo large to us, and ſhines ſo brightly beyond all the *Stars*, and in bigneſs ſeems to equal the *Sun*, is owing intirely to her nearneſs to the *Earth*; for a Spectator in the *Sun*, would ſcarcely be able to obſerve her without a Teleſcope, and therefore if ſhe were as far removed from us as the *Sun*, ſhe would be ſo ſmall as ſcarcely to be viſible by an Eye that is not aſſiſted by a Glaſs.

Jupiter's *four* Moons.

JUPITER has four *Moons* that attend him, which at different Diſtances, and with different Periods, perform conſtant Circulations round him; that which is next to him, is no further removed than 2 $\frac{5}{8}$ of his own Diameters, and turns round in one Day, eighteen Hours and an half. The 2d, at the Diſtance of 4$\frac{1}{2}$ Diameters, deſcribes its Orbit in the ſpace of three Days, and thirteen Hours. The 3d is removed from *Jupiter*, ſeven of his Diameters, and finiſhes his Circulation in ſeven Days, four Hours. The furthermoſt compleats his Period in the ſpace of 16 Days, 16$\frac{1}{2}$ Hours, at the Diſtance of 12 Diameters of *Jupiter*.

THESE Jovial Planets were firſt obſerved by that Noble *Italian* Philoſopher *Galileus*, by the help of the Teleſcope which he firſt Invented, and by them he encreaſed the number of the Celeſtial Bodies, and called them *Medicean* Stars, in honour of the Dukes of *Tuſcany*, with whoſe Name he dignified them. By the benefit of theſe new diſcovered Worlds, *Aſtronomy* and *Geography* have received many particular Advantages.

Saturn has *five* Moons.

SATURN performs his Courſe round the Sun with no leſs than five Attendants, tho' moſt of them by reaſon of their great Diſtance from the Sun, and the ſmallneſs of their own Bodies, are not to be ſeen but by the help of very long Teleſcopes: The acute Eyes of Mr. *Coſſini* the *French* King's *Aſtronomer*, were the firſt that reached all that have been already diſcovered; and but of late they have been ſeen in *Britain*, by means only of that Teleſcope which was given to the ROYAL SOCIETY by the Illuſtrious M. *Hugens*. The Diſtances of theſe Planets from *Saturn*, and their Periodical times, are as followeth. The neareſt compleats his Revolution in one Day and $\frac{7}{8}$, and is diſtant from *Saturn*'s Center $4\frac{3}{8}$ of his Semidiameters. The 2d revolves about *Saturn* in 2 Days 17 Hours, and the Semidiameter of his Orbit is $5\frac{3}{5}$ of the Semidiameters of *Saturn*. The 3d finiſhes his Revolution in 4 Days and 12 Hours, at the Diſtance of 8 Semidiameters. The 4th compleats his Period in 16 Days, and is diſtant from *Saturn* 18 of his Semidiameters. The 5th and outermoſt takes $79\frac{1}{3}$ Days to finiſh his Courſe, and is 54 Semidiameters of *Saturn* diſtant from him.

Saturn's *Ring*.

BESIDES theſe Attendants, *Saturn* has an Ornament peculiar to himſelf, for he is dignified with a *Ring* which ſurrounds his middle, and does no where touch his Body; but by an exact Libration and Equiponderancy of all its Parts, ſuſtains it ſelf like an Arch, and being thus ſuſpended by *Geometry*, it is kept from falling upon his Body. The Diameter of this Ring, is more than double of the Diameter of *Saturn*; and tho' the thickneſs of this Ring on the convex or concave ſide be but ſmall, yet its breadth or depth is ſo great, that it takes up the half of that Space which is between its outward Surface and the Body of *Saturn*, the reſt of the Space remaining void: So that in proper Situations we can ſee the Heavens between the Ring and the Body. For what purpoſe this admirable Ring was made, we know not; and perhaps we never may come to the Knowledge of it, ſince we find nothing in Nature like it: But yet we cannot but admire the Infinite Majeſty and Power of GOD, who in this our Age, has diſcovered and ſhewed us new and unthought of Inſtances of his Greatneſs.

LECTURE IV.

In which is proved that the Syſtem Explained in the former Lecture, *is the true Syſtem of the World.*

IT may perhaps be objected againſt the Syſtem of the World delivered in our laſt Lecture, that we feigned and imagined our Spectator carried up into Heaven, and from thence to have ſeen with his Eyes the Motions, Situations, and Order of the Planets which we there Explained. But this was only done in Imagination, and therefore being nothing but a Fancy or Fiction, the Syſtem we have given upon that Suppoſition, will be likewiſe only a Fiction or Hypotheſis, and may not anſwer to the Reality of Things. Can there not, by the ſame liberty of Fancy, any other Order of the Planets be ſuppoſed, and another Syſtem be given quite different from ours? Cannot

not we relying upon our Senſes, place the Earth in an immoveable Poſition, and ſuppoſe the Sun and Planets, and all the Stars to move round it, as our Eyes teſtifie to us that they do, and from ſuch Poſitions cannot we explain all the Appearances of their Motions?

I Anſwer, that altho' we fancied our Spectator raiſed up to the Heavens, and from thence to have looked upon the Sun and Planets; yet the Order, Motions and Poſitions of the Planets, which would be ſeen upon that Suppoſition, and which we explained in the preceding Lecture, is no Fancy, or Fiction of the Imagination, but is as real, certain, and indubitable, as if a Spectator were there, and ſaw it with his Eyes. A true *Aſtronomer* feigns nothing without ſolid and ſufficient Reaſons, he takes Nature for his Guide and Rule, and lays his foundations on Obſervations: He raiſes his Syſtem upon Phyſical Cauſes, and invincible *Geometrical* demonſtrations, with which, as with an indiſſolvable Cement, he joins and binds the whole Fabrick together. The *Hypotheſes* of *Ptolemy* and *Tycho* may truly be called Fictions, for they have nothing in them but a bare Suppoſition, on which without any reaſon they depend; and they diſtort, and diſorder the whole frame of Nature. But the true *Aſtronomy* is the moſt Antient of all, for it was preſerved in the School of the *Pythagoreans*, to whom it was delivered by the firſt *Aſtronomers*, either *Ægyptians* or *Chaldeans*: It has all its Parts fitly joined together in a moſt agreeable Harmony and Order; it leads us to the knowledge of the Univerſe, and the wonderful Symmetry, Beauty and regular diſpoſition of all the Bodies that compoſe it. There is nothing in Nature that does more ſhow the peircing Force of Human Underſtanding, the ſublimity of its Speculations and deep reſearches, than true *Aſtronomy*. It raiſes our Minds above our Senſes, and even in contradiction to them, ſhows us the true Syſtem of the World: The faculty of Reaſon by which we have

True Aſtronomy admits of no Fictions, or Hypotheſis.

made theſe great diſcoveries in the Heavens, muſt needs be derived from Heaven, ſince no Earthly Principle can attain ſo great a Perfection. And ſince the Origination of our Minds is from Heaven, it may be expected that they will endeavour to return thither, and Heaven will become our final Habitation: We will here declare in few Words, ſome of the ways by which the Mind arrived to the knowledge of theſe Heavenly diſcoveries.

A Demonſtration that the Planets turn round the Sun.

FIRST, it is certain that wherever the Sun be placed the Orbit of *Venus* does ſurround him, and includes him within it ſelf; and therefore *Venus* while ſhe deſcribes this Orbit, does really turn round the Sun; for *Venus* has been obſerved to be above or beyond the Sun, ſometimes it has been ſeen below it or between the Sun and us. That *Venus* aſcends above the Sun is plain from hence, that when ſhe is in Conjunction with the Sun, that is when ſhe is ſeen from the Earth near the ſame part of the Heavens that the Sun is in, her lucid Face appears in a full and round Figure: For ſince all the Planets borrow all the Light with which they ſhine, from the Sun, it is neceſſary that that Face of hers ſhould be lucid which is towards the Sun, and that which is turned from him, be involved in Darkneſs; and therefore when ſhe Shines with a full and round Face, that ſide of her which is towards the Sun is alſo towards the Earth; and therefore at that time ſhe muſt be above the Sun, for in no other Poſition could her illuminated Face be towards the Earth, when ſhe is ſeen in Conjunction with the Sun. In the Figure let S repreſent the Sun, T the Earth, and let *Venus* be in F or V, where ſhe can be ſeen from the Earth, in the ſame part of the Heaven that the Sun is, and ſhe will appear to have a full and round ſhining Face; becauſe that ſide of her which is illuminated, and is towards the Sun, is likewiſe turned towards the Earth; and therefore the Place of *Venus* in that caſe, muſt neceſſarily be above the Sun. That

Plate II. Fig. 2.

Venus is alſo ſometimes below the Sun, or between the Sun and us, is evident from hence; that ſometimes when ſhe is in Conjunction with the Sun, ſhe either quite diſappears, or if ſhe is viſible, ſhe appears Horned and takes exactly the ſhape of a new Moon: And therefore that Face of hers which is towards the Sun, either is wholly turned from the Earth as in G; or only a very ſmall part of the illuminated Face is towards the Earth, and can be ſeen by its Inhabitants, in which caſe ſhe aſſumes a horned Figure as the Moon does; and therefore at that Time ſhe muſt of neceſſity be placed between the Sun and us, and come lower or nearer to us than the Sun is. Once *Venus* was ſeen within the body or disk of the Sun; but there was but one Man who had the happineſs to be witneſs of the Sight, our Country-Man Mr. *Horrox*, who in the Year of Chriſt 1639, obſerved it with his Teleſcope to enter upon the Body of the Sun like a black Spot. This is a Sight which can ſeldom be obſerved, for it will not be ſeen again in the Sun's Body, 'till the Year 1761, upon the 26th day of the Month of *May* in the Morning, at which time all our *Aſtronomers* will no doubt be buſie in making their Obſervations; for by them our Diſtance from the Sun can be nearly determined, which before that Time is not eaſily to be aſcertained. Beſides this, *Venus* is always obſerved to keep near the Sun, and in the ſame quarter of the Heavens that he is, for ſhe never recedes from him beyond a certain Diſtance of about 45 Degrees; that ſo ſhe never comes in Oppoſition to the Sun, or to be ſeen in the *Eaſt* when he is in the *Weſt*; nay, ſhe never attains or arrives at a Quartile Aſpect with him, or to have a fourth part of the Heaven between her and him, which would neceſſarily happen, did ſhe perform her Period round the Earth in either a longer, or ſhorter time than the Sun does.

The Appearances of Mercury *are like thoſe of* Venus.

AFTER the ſame manner *Mercury* always keeps himſelf in the Neighbourhood of the Sun, and never recedes from him ſo far as *Venus* does, he hides himſelf ſo much in the Splendor of the Sun's Rays, that he is but ſeldom ſeen by us on the Earth; but ſince the Invention of Teleſcopes, he has been frequently obſerved, when in Conjunction with the Sun, to paſs under his disk like a black Spot, as *Venus* was ſeen by Mr. *Horrox*: The exceeding Brightneſs by which *Mercury* out-ſhines all the Planets, does evidently prove him to be much nearer the Sun, than any of the reſt; for the nearer any Body is to the Sun, the greater is the Illuſtration it received from him. From all this it is evident, that *Mercury* does likewiſe go round the Sun in a leſſer Orbit, included within the Orbit of *Venus*; which therefore muſt neceſſarily be his Place, for no other can be aſſigned him.

The Orbit of Mars *includes the* Sun *within it, and likewiſe the* Earth.

MARS is not like *Mercury* and *Venus*, for he often comes in Oppoſition to the Sun, and appears to Riſe in the *Eaſt*, when the Sun Setts in the *Weſt*, and therefore his Orbit includes the Earth within it, and not only the Earth, but it neceſſarily includes the Sun likewiſe; for *Mars* when he is ſeen near the Conjunction with the Sun, if he were between the Sun and Earth, would either quite diſappear, or appear Horned in the ſame Shape that *Venus* and the Moon have in that Poſition: But he always preſerves a full, round and ſhining Face, except near his *Quadrat Aſpect*, that is, when there is about a fourth part of the Heavens between the Sun and him; then he is obſerved to be ſomewhat gibbous, like the Moon, three or four days before or after the *Full*.

Plate II. Fig. 3.

LET S repreſent the Sun, T the Earth, and the Circle MNPR the Orbit of *Mars*; it is plain that *Mars* in both M, and P, muſt ſhine with a full Face upon the Inhabitants of the Earth, becauſe that in both theſe Poſitions his Face, which is towards the Sun, and by it Illuminated, is likewiſe towards the Earth: But in N and R, he will appear a little gibbous or deficient from Full. Beſides *Mars* when he is ſeen in Oppoſition to the Sun, looks almoſt ſeven times larger, in Diameter than when he is near to a Conjunction with him; and therefore he muſt needs be ſeven times nearer to the Earth in the one Poſition than in the other: From hence it is plain, that tho' the Earth lies within the Orbit of *Mars*, yet it is not near to the Center of his Orbit; but *Mars* always keeps nearly at the ſame Diſtance from the Sun, and therefore it is evident, that it is not the Earth, but the Sun which *Mars* reſpects as the Center of his Motions: For *Mars* ſeen from the Earth appears to move very unequally, ſometimes to go faſter, ſometimes ſlower, ſometimes he ſcarcely ſeems to move at all, and ſometimes he even goes with a backward Motion; whereas a Spectator in the Sun, would always ſee *Mars* go forward in the ſame uniform tenor, and therefore it is moſt evident that the Sun is the Center, and not the Earth, of *Mars*'s Motions. Again, ſince the ſame Appearances are obſerved in *Jupiter* and *Saturn*, as in *Mars* (tho' the diſproportion, or difference of the Diſtances is not ſo great in *Jupiter* as in *Mars*; nor ſo great in *Saturn* as it is in *Jupiter*) and the Motions of theſe two Planets are no ways uniform round the Earth; yet from the Sun their Motions will be ſeen to be regular and orderly: It is plain from hence that the Sun, and not the Earth, is in the Center of all the Orbits of the Planets. The place of the Earth we have demonſtrated to be without the Orbits of *Mercury* and *Venus*; and within the Orbit of *Mars*; and therefore its Place muſt needs be between the Orbits of *Venus* and *Mars*: And from thence it follows, that the Earth it ſelf muſt turn round the Sun, for if it ſtood ſtill, ſince it lies within the Orbits of the ſuperior Planets *Mars*, *Jupiter*, and *Saturn*, we might indeed obſerve the Motions of thoſe Planets from the Earth, to be very unequal and irregular, but they would never appear to ſtand ſtill, or to go backwards, ſo long as the Orbits themſelves are quieſcent, as we demonſtrated in our firſt Lecture. Since therefore the Stations, and Retrogradations

The Earth *is not in the Center of* Mars's *Orbit.*

The ſame Appearances of Jupiter *and* Saturn.

The Earth moves in an Orbit round the Sun.

tions of theſe Planets are obſerved from the Earth: and ſince the Poſition of the Earth, or place that it obtains in the Syſtem, is in the middle of the moveable Bodies, having *Mercury* and *Venus* on one ſide nearer to the Sun, and *Mars*, *Jupiter*, and *Saturn* on the other ſide more remote; it being of the ſame nature as they are, muſt likewiſe have the ſame ſort of Motions; and as the Earth is in the middle place between *Venus* and *Mars*, ſo its Period likewiſe in which it performs its Courſe round the Sun, is alſo a mean between the Periods of *Venus* and *Mars*, being greater than the one, and leſs than the other: For *Venus* deſcribes her Orbit in eight Months; the Earth in a Year; but *Mars* takes near two Years to finiſh his Courſe.

A Demonſtration of the Earth's Motion.

THERE is another demonſtration of the Earth's Motion drawn from Phyſical Cauſes, for which we are indebted to the admirable diſcoveries of the Incomparable *Sir* ISAAC NEWTON: He has demonſtrated that all the Planets Gravitate towards the Sun: And obſervations teſtifie to us, that either the Earth turns round the Sun, or the Sun round the Earth, in ſuch a manner as that they deſcribe equal *Area's* in equal Times. But *Sir* ISAAC has demonſtrated that when ever Bodies turn round each other, and regulate their Motions by ſuch Law, the one muſt of neceſſity Gravitate to the other; and therefore if the Sun in its Motion does Gravitate to the Earth, Action and Re-action being equal and contrary, the Earth muſt likewiſe Gravitate to the Sun: He has likewiſe demonſtrated that when two Bodies Gravitate to one another, without directly approaching one another in right Lines, they muſt both of them turn round their common Center of Gravity. The Sun and Earth therefore do both turn round their common Center of Gravity. But the Sun is ſo great a Body in reſpect of the Earth, which is but a Point as it were in compariſon of the Sun, that the common Center of Gravity of the Earth and Sun, muſt lye within the Body of the

Sun its ſelf, and not far from the Center of the *Sun*: The *Earth* therefore turns round a Point which is within the Body of the *Sun*, and therefore turns round the *Sun*. This Argument drawn from Phyſical Cauſes I take to be unanſwerable.

COMPARING the Periods of the *Planets*, or the Times they take to finiſh their Circulations, with their Diſtances from the *Sun*, we find they obſerve a wonderful Harmony and proportion to one another; for the nearer that any *Planet* is to the *Sun*, the ſooner does he finiſh his Circulation, and his Motion is the quicker: And in this there is a conſtant and immutable Law, which all the Bodies of the Univerſe inviolably obſerve in their Circulations. *Viz.* That *The Squares of their Periodical Times, are as the Cubes of their Diſtances from the Center of their Orbits, about which they perform their Motions regularly.* The moſt ſagacious *Kepler* was the firſt who diſcovered this great Law of Nature in all the Primary *Planets*; afterwards the *Aſtronomers* obſerved that the Secondary *Planets* did likewiſe regulate their Motions by the ſame Law; and that in the two Syſtems of Bodies revolving about *Jupiter* and *Saturn*, this Rule is conſtantly obſerved, that the Squares of their Periodical Times are as the Cubes of their Diſtances from their reſpective Primaries. Thus the *Moon* or *Satellite* that is next to *Jupiter*, is diſtant from *Jupiter*'s Center $2\frac{5}{6}$ of *Jupiter*'s Diameters, and he performs his Period in 42 Hours. The outermoſt *Satellite* deſcribes his Orbit in 402 Hours. Say therefore as 1764 the Square of 42, is to 161604 the Square of 402; ſo is $\frac{4913}{216}$ the Cube of $2\frac{5}{6}$, to a fourth proportional Number, which by the *Golden Rule* will be found nearly $\frac{450000}{216}$; out of which number extract the cube Root, and we have $\frac{76}{6}$ or $12\frac{2}{3}$ for the Diſtance of the furthermoſt *Satellite* from *Jupiter*. Now the Obſervations of all *Aſtronomers* confirm, that this is the true Diſtance of that *Satellite* from the Center of *Jupiter*, and the ſame thing is to be obſerved

A wonderful Harmony obſerved between the Periods of the Planets, *and their Diſtances from the* Sun.

in all the reſt, as likewiſe in the *Satellites* of *Saturn*.

THE reaſon of this Law was unknown to *Kepler*, for he found it out only by Computation, comparing the Diſtances of the *Planets* with their Periods. But the Glory of inveſtigating it from its proper Cauſe, and demonſtrating the Phyſical Neceſſity of this Law, was reſerved for the Great Sir ISAAC NEWTON, who has demonſtrated, that without a total Subverſion of the Laws of Nature, no other Rule could take place in the Circulations of the Heavenly Bodies.

Sir Iſaac Newton *firſt diſcovered the reaſon and Cauſe of this Harmony.*

SINCE therefore all *Aſtronomers* do unanimouſly agree that the Law we have above explained is conſtantly obſerved by 14 great Bodies, of which there are more than one that turn round a common Center, *viz.* five Primary *Planets* and nine Secondaries. And ſince the *Moon* turns round the *Earth*, if the *Sun* did likewiſe perform his Circuits round it, according to this Law of Nature, the *Moon* and *Sun* ought to regulate their Motions in the ſame manner; and therefore ſince the *Moon* finiſhes her Courſe in 27 Days, and the *Sun* in 365, and the Diſtance of the *Moon* is known to be about 60 Semidiameters of the *Earth*; if we ſay, as 729 the Square of 27 is to 133225 the Square of 365, ſo is 216000 the Cube of 60 to another which will be 39460356, the cube Root therof being 340 ought to expreſs the Diſtance of the *Sun* from the *Earth*, provided he governed his Motion by the ſame Law that all other Bodies do. Now the *Aſtronomers* prove by invincible Reaſons that the *Sun* is more than 30 times further from the *Earth* than 340 Semidiameters of the *Earth*; for it cannot well be ſuppoſed ſo little as 10000 Semidiameters: According to which Diſtance it could not turn round the *Earth* in leſs than 54700 Years, if it obſerved the ſame Law which all other Bodies do.

NOW it is certain that the *Sun* does either turn round the *Earth*, or the *Earth* round the *Sun* once in a Year. But if the *Sun* ſhould be made to turn round the *Earth*, the Univerſal Law of Nature would thereby be violated, the Harmony and Proportion of the Motions deſtroyed, and a Confuſion and diſorder introduced into the Frame of the Univerſe. But if the *Earth* be made to go round the *Sun* in the ſpace of a Year, it will then perform its Circulation according to the ſame Law which the other *Planets* obſerve; and without the leaſt exception there will be a moſt beautiful order and Harmony of Motions every where preſerved thro' the whole Frame of Nature.

If the Sun *turned round the* Earth, *this Harmonical Rule would not univerſally hold.*

AS we diſcover the mutual Relations and likeneſs of Nature that is in the *Planets*, in that they are like our *Earth*, Opake, Spherical Bodies, which are illuſtrated and ſhine with the borrowed Light of the *Sun*, round whom they all Circulate, as we have ſaid, with a regular Harmony and order: So likewiſe the *Sun* and all the *fixed Stars* which ſhine with their own native Light, and remain immoveable in their Places, are to be conſidered as Bodies of the ſame kind and Nature: The reaſon why our *Sun* appears to us ſo great and bright in compariſon of the *Stars*, whoſe weaker Lights diſappear as ſoon as the *Sun* begins with his Beams to refreſh and illuſtrate our Habitation, is, that the *Earth* at an immenſe Diſtance from all the reſt of the *Stars*, keeps near to the *Sun*, round whom ſhe always circulates; for a Spectator placed as near any of them as we are to our *Sun*, would ſee a Body as big and bright as the *Sun* appears to us, and every way like our *Sun*. A Spectator as far diſtant from our *Sun* as the *fixed Stars* are from us, would obſerve our *Sun* as ſmall as a *Star*, and no doubt would reckon the *Sun* as one of them in numbering the *Stars*. All the *fixed Stars* therefore are *Suns*, and the *Sun* differs in nothing from a *fixed Star*.

ALTHO' the *Earth* is at ſuch a Diſtance from the *Sun,* that if it were to be ſeen from his Body it would appear no bigger than a Point, yet that Diſtance is ſo very ſmall in compariſon of the exceeding great Diſtance of the neareſt *fixed Star,* that if the whole Orbit, in which we have ſaid the *Earth* moves round the *Sun,* were ſeen from a *Star,* it would appear likewiſe no bigger than a Point. For the Angle under which the whole Diameter of the *Earth*'s Orbit appears is ſo very ſmall, that our quickeſt and moſt ſharp ſighted *Aſtronomers* can ſcarcely obſerve it. They who have been moſt diligent in obſerving this Angle (which they call the Parallax of the great Orbit, that is of the Orbit in which the *Earth* moves) have always found it to be leſs than a Minute, and therefore the *fixed Stars* muſt be at leaſt 10000 times further from us, than we are from the *Sun.*

HENCE it follows, that tho' the *Earth* approaches nearer to ſome *fixed Stars* at one time of the Year, than it does at the oppoſite Time, and that by the whole interval of the Diameter of its Orbit, the *Stars* will not upon that account ſeem bigger when it is neareſt to them, nor will the viſible Poſition of any two *Stars* be ſenſibly changed by the Motion of the *Earth.* For even here on *Earth*, if there be two Towers that are near to one another, if they are to be ſeen by a Spectator who is ten Miles diſtant from each, if this Spectator approach near to them only by one Pace, which is the 10000th part of the Diſtance, he only approaching by ſo ſmall a Space, can no ways perceive the Towers bigger, or their Diſtance from one another greater. After the ſame manner the *Earth* approaching a *fixed Star,* and coming nearer to it by the 10000th part of the Diſtance between the *Earth* and it, a Spectator on the *Earth,* upon the account of ſo ſmall a change of Place, will not find thereby any ſenſible difference either of the Magnitude, or Poſition of the *Star.*

The Angle under which the Sun *would appear ſeen from a* fixed Star.

HENCE it follows, that if the *Sun* were as far diſtant from us as the *Stars* are, that is 10000 Semidiameters of the *Earth*'s Orbit, it would appear 10000 times leſs or under a ſmaller Angle than it does now: Now the Angle under which the *Sun* appears to us, is about half a Degree or 30 Minutes; if the *Sun* were removed as far from us as the *fixed Stars* are, he would be ſeen under an Angle of but the thouſandth part of three Minutes, that is under an Angle no bigger than ten *Thirds*, which is altogether imperceptible; and no bigger would the Angle be under which a Spectator placed among the *fixed Stars* would obſerve the *Sun*.

AGAINST this Poſition of ours ſome may object, that if the Diſtance of the *Stars* be ſo great, they themſelves muſt be vaſtly larger than our *Sun*; for they cannot according to them be leſs than a Sphere, whoſe Semidiameter equals the Diſtance between the *Sun* and us; for they aſſert, that the *Stars*, at leaſt thoſe of the firſt Magnitude, are ſeen under an Angle at leaſt of one Minute: But the Orbit of the *Earth* ſeen from the *fixed Stars* does not ſubtend a greater Angle, and therefore the Diameter of the *Stars* is not leſs than the Diameter of the *Earth*'s Orbit. Now that Sphere whoſe Semidiameter equals the Diſtance between the *Sun* and *Earth*, is ten Millions of times greater than the *Sun*; conſequently the *fixed Stars* muſt be at leaſt ten Millions of times greater than our *Sun*: Since therefore there is ſuch enormous difference in their bigneſs, it cannot be ſuppoſed that the *Sun* and *fixed Stars* are Bodies of the ſame kind.

The fixed Stars *have no Apparent Diameters, but look like Points.*

BUT they who aſcribe ſuch immenſe Magnitude to the *fixed Stars*, are much deceived in their Meaſures, for their Apparent Diameters are not near ſo great as they ſuppoſe them to be: For really theſe Diameters are ſo extreamly ſmall, that if they be rightly obſerved, they appear like ſo many ſhining Points without any Breadth or Diameter at all; and there can be no Obſervations nice enough, by which the minuteneſs of their Diameters can be meaſured, or reduced to any determined quantity. We obſerve about all flaming and ſhining Bodies in the Night, a kind of irradiation or luminous Appearence, by which their Diameters are ſeen a Hundred or many more times bigger than they are; as it is plain by the Experiment of a Candle placed at a great Diſtance, whoſe Flame ſeems to be much larger than it is when we come near it. This irradiation is much diminiſhed if they are looked at thro' a ſmall hole made with a Pin in Paper, but it is eaſier and more nicely taken away when they are ſeen thro' a Teleſcope, which deſtroys the adventitious Rays, and ſhews us the *fixed Stars* as ſo many lucid Points. Now tho' Teleſcopes do encreaſe the Diameters of Bodies very much, yet the *fixed Stars* ſeen thro' them appear ſtill ſo ſmall, that we have no meaſure of any determined Magnitude but what is greater than theirs ſeem to be; a Teleſcope magnifying a Hundered times ſhews them only like ſhining Points; and therefore I cannot but wonder why *Riceiolus* ſhould ſuppoſe the Apparent Diameter of the *Dog-Star* or *Sirius* to be 18 Seconds; for if that were the Angle he ſubtended to the naked Eye, a Teleſcope which Magnifies 200 times, would ſhew that *Star* under an Angle of 3600 Seconds or one Degree, ſo that he would appear to have a Disk four times greater than the *Sun* and *Moon* have: And yet Obſervation teſtifies that ſuch a Teleſcope ſhews us *Sirius* no bigger than a Point, at leaſt not larger than the Planet *Mars*: But *Mars*, when he is neareſt us and biggeſt, ſubtends an Angle of about 30 Seconds; therefore if the Diameter of *Sirius* magnified 200 times is but 30 Seconds, its Apparent Diameter without magnifying will be the 200th part of 30 Seconds, or $\frac{3}{20}$ of a Second, that is nine Third Scruples or Minutes, or nearly equal to the *Sun* when it is ſeen at the Diſtance of the *fixed Stars*, as we ſhewed before: The

Which is demonſtrated by the Teleſcope.

Sun therefore and *Sirius* are nearly of the ſame Magnitude and Dimenſions, and may be eſteemed Bodies of the ſame kind.

SINCE the *fixed Stars* appear ſo ſmall, and ſubtend at the Eye ſuch unperceiveable Angles, ſome will wonder how they come to be at all ſeen, ſince there are Bodies which would ſhow themſelves under larger Angles that are yet ſo ſmall, as not to be looked at without a Microſcope: But all flaming and fiery Bodies can be ſeen at great Diſtances, even at ſuch from whence other Bodies which have as large apparent Diameters do quite diſappear, and become Inviſible. Thus the Flame of a Candle in the Night time is eaſily perceived at the diſtance of two Miles, whereas in the Day time an opake Object, tho' ſtrongly illuſtrated by the *Sun*, and ſix times bigger than the Flame of a Candle, is not to be obſerved with the naked Eye at that Diſtance. For the native Light that theſe fiery and flaming Bodies ſend forth, is ſtronger and more peircing, and acts upon the nervous Fibres of the *Retina* with a greater Force, than the Light reflected from opake Objects; for all Light is much weakened by Reflection. And it is upon the account of this brisk and ſtrong Light which flows from fiery Bodies, and which makes ſo ſenſible Impreſſions on the *Retina*, that ſuch Bodies are judged to be ſo big in compariſon of others which affect us with a weaker Light.

The fixed Stars *are Luminous fiery Bodies.*

HENCE it is evident that all theſe *Stars* which remain immoveable in the Heavens are Bodies of a fiery nature, as our *Sun* is, nor are they much leſs, nor much bigger than he is, and therefore are to be eſteemed as ſo many *Suns*. It is not to be imagined that all theſe *Suns* are planted in one concave Surface of a Sphere, ſo as to be all equally diſtant from us; but it is more reaſonable to ſuppoſe that they are ſpread every where thro' the vaſt Indefinite ſpace of the Univerſe, and that they are at great Diſtances from one another; ſo that there may be as great Diſtance

The fixed Stars *are* Suns.

between any two *Suns* that are next to one another, as there is between our *Sun* and the neareſt *fixed Star*. Hence a Spectator who is near any one *Sun*, will only look upon him to whom he is neareſt as a real *Sun*, and the reſt he will conſider as ſo many ſmall ſhining *Stars* fixed in his Heaven or Firmament.

IT is no ways probable that GOD Almighty who always acts with infinite Wiſdom, and does nothing in vain, ſhould create ſo many *Suns*, and place them alone in indefinite Space, at ſuch great Diſtances from each other, and not have made other Bodies, which he has placed near them, to be nouriſhed, animated and refreſhed with the Heat and Light of theſe *Suns*: Thoſe who affirm that GOD created theſe great Bodies only to give us a ſmall dim Light, muſt have a very mean Opinion of the Divine Wiſdom. It is more reaſonable to ſuppoſe that every *Sun* is ſurrounded with a company of *Planets*, peculiar to himſelf, which in different Periods, and at different Diſtances, perform their Circulations round their proper *Sun*; and who knows but that ſome of theſe *Planets* may have *Moons*, and other Bodies to attend them in their Circulations?

An Idea *of the Univerſe.*

HENCE we may frame to our ſelves an admirable Magnificent *Idea* or Notion of the vaſtneſs or Amplitude of the World, by imagining an Indefinitely great Space of the Univerſe in which there are placed innumerable *Suns*, which tho' they appear to us like ſo many ſmall *Stars*, yet are Bodies which are not behind our *Sun* either in Bigneſs, Light, or Glory; and each of them conſtantly attended with a number of *Planets*, which dance round him, and conſtitute ſo many particular *Worlds* or Syſtems: Every *Sun* doing the ſame Office to his proper *Planets* in illuſtrating, warming, and cheriſhing them, that our *Sun* performs in the Syſtem to which we belong.

HENCE we are to conſider the whole Univerſe as a glorious Palace for an infinitely Great and every-where-preſent GOD; and that all the *Worlds* or Syſtem of *Worlds*, are as ſo many Theaters, in which he diſplays his Divine Power, Wiſdom and Goodneſs.

LECTURE V.

Of the Solar Spots. Of the Rotation of the Sun *and* Planets *round their* Axes: *And of the* fixed Stars.

The convexity of the Sun *and* Moon *cannot be perceived by our Eyes.*

UPON the account of the great Diſtance of the *Sun* from us, the convexity of his Body cannot be perceived by our ſight; nor is this a wonder, ſince the *Moon* which is much nearer to us cannot be ſeen as a globular Body: But both *Sun* and *Moon* ſhew themſelves to us as if they were circular Planes, which we call Disks: And a Point in the middle, which is really in the Surface, is ſaid to be the Center, or the Apparent Center of the Disk.

Dark Spots on the Sun's *Body.*

IF the *Sun* thro' all its Parts were every where equally bright, and ſhined with the ſame Luſtre, he might turn round his own *Axis*, and that Rotation no ways be perceptible, nor to be diſcovered by our Senſes. But ſince in the moſt clear and lucid Body of the *Sun*, and in its pureſt Flame, many black Spots have ſeveral times been obſerved, it is by their Motion that we diſcover the Rotation of the *Sun* round his *Axis*: For theſe Spots have been obſerved to have firſt appeared near the Margin of the *Sun*, and then by degrees to have crept towards the middle, or Center of his Disk; and from thence going ſtill forward have arrived at the oppoſite ſide or edge of the Disk, where they have Set or diſappeared;

and ſome of them after ſetting, being hid or abſconded in the oppoſite ſide of the *Sun* for the ſpace of about fourteen Days, have again appeared in the Margin, and ſhewed themſelves, taking the ſame Courſe as before. Let the Circle Plate II. Fig. 4. A G H D repreſent the *Sun*'s Disk, we often obſerve ſome denſe and obſcure Subſtances, like our thick and Terreſtial Clouds, to appear in the Limb or edge at A, which by degrees move towards B, and at laſt arrive at the middle of the Disk; after which ſtill going forward, they ſhew themſelves in the oppoſite Point of the Circumference at D; where after a little ſtay, they at laſt vaniſh and diſappear.

SOME of theſe Spots have been obſerved to Riſe in the Limb, and having traverſed the Disk and Set, after the ſpace of twenty ſeven Days, have again been ſeen to Riſe where they firſt appeared; and the time they take to move thro' the Surface of the *Sun* oppoſite to us, during which time they are inviſible, is juſt equal to the time in which they paſs over the viſible Disk. The Motion of theſe Spots in the Margin, at A or at D, appears to be ſlow; when they come towards the middle they ſeem to move quicker, and to deſcribe larger Spaces; their Figures likewiſe change, for in the Limb they are ſeen more contracted and narrow, near the Center they look broader and larger; theſe Appearances exactly anſwer to the Motion of ſome denſe and dark Bodies, which Swim upon the Surface of the *Sun*, and are whirled by the vertiginous Motion of the *Sun* round his *Axis*.

The Sun *turns round his* Axis.

SOME have imagined that theſe Spots do not ſtick upon the Body of the *Sun*, but that they are at ſome Diſtance from him, and that they perform their Circulations round the *Sun* in the ſame manner as *Jupiter*'s *Satellites* Circulate round *Jupiter*: But ſuch are eaſily refuted, for if the Spots were not on the Body of the *Sun*, but made their Circuits at a Diſtance from him, they could not be ſeen half the time of their Period in the Body of the *Sun*; for ſuppoſe the *Sun* in A be ſeen from the *Earth* at B, under an Angle of 30 Minutes: If the Spot were not on the *Sun*'s Body, but deſcribed the Circle F E G at ſome Diſtance from him; it could not be obſerved to paſs under the *Sun* 'till it came to E, where the right Line B D touching the Diſk does cut the Orbit; and if we draw another Tangent to the Diſk B G C, it would only be ſeen on the Surface of the *Sun*, while it deſcribed the Arch E G, which is much leſs than half the Periphery, and is deſcribed in much leſs time than half the Period, in which the Spot performs its Circuit. Now we know by Obſervation that thoſe Spots which finiſh an intire Circulation (for ſome of them have been obſerved to make four or five compleat Revolutions before they were diſſolved, each of which was 27 Days) have taken 13½ Days from the time of their appearing, or riſing on the *Eaſtern* Limb, to their Setting on the *Weſtern*: And therefore ſince the Spots are ſeen for half the time of their Period upon the Body of the *Sun*, it is plain their Orbits muſt lye on the *Sun*'s Surface.

Plate II. Fig. 5.

The Spots are on the Surface of the Sun.

MANY Spots ſeem to be generated in the very middle of the Diſk, where they firſt begin to appear: Others again ſeem to be diſſolved and to vaniſh there; ſometimes ſeveral ſmall ones gather together and make a large Spot, and ſometimes a large Spot is ſeen to be divided, and cut into many leſſer ones. The Great *Italian* Philoſopher *Galileus*, firſt diſcovered them with his Teleſcope. Afterwards *Scheinerus* did more accurately obſerve them, who has publiſhed a large Volume about them. When he obſerved them, there were then 50 viſible in the *Sun*: From the Year 1650 to the Year 1670, there was rarely ſeen above one or two together; from that time again many have been obſerved together; nor does there ſeem to be any certain Period of Time, or Law for their appearing, and vaniſhing or diſſolution.

Spots generated in the Body of the Sun, *and again are there diſſolved or diſſipated.*

Lect. V.

The Sun has ſometimes appeared Pale for a Year together.

HISTORIANS tell us that the *Sun* has been obſerved for a whole Year to have appeared Pale, without that Luſtre and brightneſs it uſually gives; and that it hath not imparted its Heat and Light with the ſame Force and vigour that it ordinarily does. It is probable that this weakneſs of Light did ariſe from a great multitude of Spots which at that time did beſet the *Sun*, and covered a large Portion of his Surface: For now we frequently obſerve Spots which are larger or broader, not only than *Europe* or *Africk*, but what even equal, if they do not exceed, the Surface of the whole *Terraqueous* Globe.

The Axis of the Sun is inclined to the Plane of the Eclip-tick.

THE Motion of the Spots is from the *Weſt* to the *Eaſt*, and by obſerving the *Sun* nicely, we find that its *Axis* is not Perpendicular to the Plane of the *Earth*'s Orbit, which is called the Plane of the *Ecliptick*: But it is inclined ſo, as to make an Angle with the *Axis* of the Orbit, or with a Perpendicular to the Plane of the Orbit which paſſes thro' the Center of the *Sun*, which Angle is in quantity about ſeven Degrees: And therefore the Æquator of the *Sun*, that is to ſay, the Circle which is in the middle between the two Poles, cuts the Plane of the Orbit in a right Line, which Line produced will interſect the Orbit in two Points; and whenever the *Earth* comes to theſe two Interſections, the Tracts which the Spots deſcribe will appear as right Lines, ſince the Eye of the Spectator is in the Plane of their Motion: But in all other Poſitions of the *Earth*, the Plane of the *Sun*'s Æquator is either above or below the Eye of the Spectator, and the Lines in which the Spots are ſeen to move, appear crooked and ſeem to be *Ellipſes*.

The Planets likewiſe have Spots.

SINCE the moſt bright Body of the *Sun* is not without its Spots and blemiſhes, we are not to imagine that the *Planets* are clear, and without their Stains and Marks. *Jupiter*, *Mars*, and *Venus*, when looked at thro' a Teleſcope, have ſeveral very remarkable ones; and it is by their Motions that we conclude the Rotation of the

Planets round their *Axes*, after the ſame manner, and by the ſame Argument, that we proved the Rotation of the *Sun*. The Body of *Venus* performs its Revolution round its *Axis* in the ſpace of 23 Hours. *Mars* finiſhes his Rotation in 24 Hours and 40 Minutes. The *Earth* in a Day, which we collect from the Apparent Revolution of the Heavens and of all the *Stars* round it in that time. All theſe Bodies in their Rotations go the ſame way from the *Weſt* to the *Eaſt*.

They turn round their Axes.

JUPITER, beſides abundance of Spots, has ſome Bands or Girdles which ſurround him; they are Parallel to one another, but they neither preſerve the ſame Magnitude nor Diſtance; but ſometimes they encreaſe, ſometimes they diminiſh their breadth, ſometimes they approach each other, ſometimes they recede from one another, and undergo ſeveral Changes. In the Year 1665, M. *Caſſini* diſcovered a very large Spot in *Jupiter*'s Disk, which he obſerved continually for the ſpace of two Years, and determined accurately its Figure and Poſition in reſpect to his Girdles, but this Spot vaniſhed in the Year 1667, and was not again ſeen 'till the Year 1672: Afterwards for the ſpace of almoſt three Years it continually ſhowed it ſelf, and then by degrees withdrew it ſelf from our ſight, and has ſince ſeveral times appeared and diſappeared. In a Word, from the Year 1665 when it was firſt obſerved, to the Year 1708, it has eight times appeared and vaniſhed. By its Revolutions we conclude, that the Body of *Jupiter* moves round his *Axis* in the compaſs of nine Hours and 56 Minutes.

Jupiter's *Belts.*

The changes he undergoes.

IT is probable that our *Earth* enjoys a more conſtant and ſettled State and condition than *Jupiter*; for we obſerve greater Changes in his Surface, than what would happen to the *Earth*, if the *Ocean* ſhould leave its Place, and overwhelm the Land, and give us a new Place, and a new figure of the Sea, by changing the places of Land and Water. But this is upon Suppoſition that theſe Spots are inherent in the Body of

Jupiter: But if they are only Clouds and Vapours ſwimming in his Atmoſphere, then indeed the Inhabitants of *Jupiter* would have a more conſtant and permanent ſtate of Weather, than what any part of the *Earth* enjoys: I leave it to the *Philoſophers* to determine which of theſe two Opinions is the moſt probable.

MERCURY does always keep ſo near the *Sun*, with ſo great a ſhining Luſtre in all his Parts; and the Heaven, while he is ſeen, is ſo much Illuminated, that there can be no Obſervations made to diſcover his Spots. And *Saturn* is ſo much further removed from us, more than the other *Planets*, that his Spots are not to be diſcerned: Yet it is probable that they, as well as the other *Planets*, have each a Rotation round an *Axis*, that all the Parts of their Surfaces may frequently have imparted to them the Light and cheriſhing heat of the *Sun*, and may again be withdrawn from him, to receive ſuch Changes as are proper and convenient for the Nature of each *Planet*.

LECTURE VI.

Of the Magnitude and Order of the fixed Stars. *Of the* Conſtellations, *Catalogues of the* Stars, *and the Changes to which they are liable.*

THE *fixed Stars* appear to be of different bigneſſes, not becauſe they really are ſo, but becauſe they are not all equally diſtant from us; thoſe that are neareſt will excell in Luſtre and Bigneſs; the more remote *Stars* will give a fainter Light, and appear ſmaller to the Eye. Hence ariſe the diſtribution of *Stars*, according to their Order and Dignity, into *Claſſes*; the firſt Claſs containing thoſe which are neareſt to us, are called *Stars* of the firſt Magnitude; thoſe that are next to them, are *Stars* of the ſecond Magnitude: The third Claſs comprehends them of the third Magnitude, and ſo forth, 'till we come to the *Stars* of the ſixth Magnitude, which comprehends the ſmalleſt *Stars* that can be diſcerned with the bare Eye. For all the other *Stars* which are only ſeen by the help of a Teleſcope, and which are called Teleſcopical, are not reckoned among theſe ſix Orders. Altho' the diſtinction of *Stars* into ſix degrees of Magnitude, is commonly received by *Aſtronomers*; yet we are not to judge that every particular *Star* is exactly to be ranked according to a certain bigneſs, which is one of the Six; but rather in reality there are almoſt as many Orders of *Stars*, as there are *Stars*, few of them being exactly of the ſame Bigneſs and Luſtre. And even among thoſe

The diſtinction of Stars *according to their Magnitude.*

those *Stars* which are reckoned of the brighteſt Claſs, there appears a variety of Magnitude, for *Sirius* or *Arcturus* are each of them brighter than *Aldebaran* or the *Bull*'s Eye, or even than the *Star* in *Spica*; and yet all theſe *Stars* are reckoned among the *Stars* of the firſt Order: And there are ſome *Stars* of ſuch an intermedial Order, that the *Aſtronomers* have differed in Claſſing of them; ſome putting the ſame *Stars* in one Claſs, others in another. For Example: The little *Dog* was by *Tycho* placed among the *Stars* of the ſecond Magnitude, which *Ptolemy* reckoned among the *Stars* of the firſt Claſs: And therefore it is not truly either of the firſt or ſecond Order, but ought to be ranked in a Place between both.

The Conſtellations.

ASTRONOMERS not only mark out the *Stars*, but that they may better bring them into Order, they diſtinguiſh them by their Situation and Poſition in reſpect to each other; and therefore they diſtribute and divide them into *Aſteriſms* or *Conſtellations*, allowing ſeveral *Stars* to make up one *Conſtellation*: A *Conſtellation* is a Syſtem of ſeveral *Stars* that are ſeen in the Heavens near to one another: And for the better diſtinguiſhing and obſerving them, they reduce the *Conſtellations* to the Forms of certain Animals; as *Men*, *Bulls*, and *Bears*, &c. or to the Images of ſome things known, as of a *Crown*, a *Harp*, a *Ballance*, *&c.* The Antients took theſe Figures from the Fables of their *Religion*: And the Modern *Aſtronomers* do ſtill retain them, that they may avoid the Confuſion which would ariſe by making new ones, which would much perplex them, when they compared the Modern Obſervations with the Old ones.

Their Antiquity.

THE Diviſion of the *Stars* by Images and Figures is of great Antiquity, and ſeems to be as old as *Aſtronomy*, or *Philoſophy* its ſelf: For in the moſt Antient Book of *Job*, *Orion*, *Arcturus*, and the *Pleiades*, are mentioned; and we meet with the Names of many of the *Conſtellations* in the Writings of the firſt Poets, *Homer* and *Heſiod.* For it was neceſſary for the Advancement of *Aſtronomy* ſo to diſtinguiſh the *Stars,* and to bring them into ſome Order.

The ſame Face of the Starry Firmament *is obſerved from all the* Planets.

SINCE the Diſtance of the *Stars* is immenſly great, it is no matter in what Place of our Syſtem the Obſerver reſides, whether in the *Sun,* in the *Earth,* or even in *Saturn,* the outmoſt of all the *Planets*; for Spectators in each of thoſe Places will ſee the ſame Face of the Heavens, the ſame *Stars,* with the ſame Magnitude, and the ſame Figure of the Conſtellations, and the Heavens which ſurrounds and involves them all, will have the ſame Face.

The Regions of the Heavens.

ASTRONOMERS divide the *starry Firmament* into three Regions, the middle of which comprehends thoſe *Stars* which have their Situation near the Planes of the Orbits in which the *Planets* move; this Part of Heaven they call the *Zodiack,* becauſe the Conſtellations there placed, ſeemed for the moſt part to repreſent ſome *Animal* or living Creature. In this Space the *Planets* are always to be ſeen, and none of them ever tranſgreſs its Bounds: Upon each ſide of this *Zone* lye the other two Regions of the Heavens, one of which is called the *North,* and the other the *south* part of the Heavens.

The Images noted by the Antients are 48.

THE Antients divided the viſible Firmament into XLVIII Images, twelve of which filled the *Zodiack,* and they give their Names to the twelve Signs, or the Portions into which it is divided. Their Names are the *Ram,* the *Bull,* the *Twins,* the *Crab,* the *Lyon,* the *Virgin,* the *Ballance,* the *scorpion,* the *Archer,* the *Goat,* the *Water-Bearer,* and the *Fiſhes.*

IN the *Northern* Region there are XXI Images, *viz.* the *Leſſer Bear,* the *Great Bear,* the *Dragon, Cepheus, Bootes,* the *Northern Crown, Hercules,* the *Harp,* the *Swan, Caſſiopeia, Perſeus, Andromeda,* the *Triangle, Auriga, Pegaſus* or the *Flying-Horſe, Equuleus,* the *Dolphin,* the *Arrow,* the *Eagle, Serpentarius,* and the *Serpent:* Afterwards

wards they added to them two others, *viz.* that of *Antinous*, which was made of the *Stars* that are not included within any Image, and are near the *Eagle*: And the Conſtellation called *Berenice's* Hair, conſiſting of *Stars* which are near the *Lyon's Tail.*

UPON the *South* ſide of the *Zodiack* there are fifteen *Aſteriſms*, which were known to the Antients, *viz.* the *Whale*, the *River Eridanus*, the *Hare*, *Orion*, the *Great Dog*, the *Leſſer Dog*, the *Ship Argo*, *Hydra*, the *Cup*, the *Crow*, the *Centaur*, the *Wolf*, the *Altar*, the *Southern Crown*, and the *Southern Fiſh*: To theſe are lately added XII more Conſtellations, which are not to be ſeen by us who Inhabit the *Northern* Regions, becauſe of the Convexity of the *Earth*; but in the *Southern* Parts they are very conſpicuous. Theſe are the *Phænix*, the *Crane*, the *Peacock*, the *Indian*, the *Bird of Paradiſe*, the *ſouthern Triangle*, the *Fly*, the *Chameleon*, the *Flying Fiſh*, the *Toucan* or *American Gooſe*, *Hydrus* or *Water Serpent*, *Xiphias* or the *Sword Fiſh*.

The Stars *without Forms.*

WITHOUT the Compaſs of the Conſtellations or Images, there are ſeveral *Stars* which cannot be reduced to any of the Forms mentioned, and theſe are called *Unformed Stars*, out of which ſome great *Aſtronomers* have made new Conſtellations, as *Charles's Heart*, and *Sobieski's Shield*.

The Milky-way.

THE *Galaxy* or *Milky-way*, is alſo to be reckoned among the Conſtellations: This is a broad Circle of a whitiſh Hue, like Milk; in ſome places it is double, but for the moſt Part it conſiſts of a ſingle Path, and goes round the whole Heavens. The Great *Galileus* with his Teleſcope, diſcovered that the Portion of the Heavens which this Circle paſſes thro', was every where filled with an infinite multitude of exceeding ſmall *Stars*, which tho' they cannot, by reaſon of their ſmalneſs, be ſeen diſtinctly by the naked Eye, yet with their Light they all combine to illuſtrate that Region of the Heavens where they are, and diffuſe thro' it a ſhining whiteneſs.

BY the help of Images, the Antient *Aſtronomers* have been able to diſtinguiſh, and mark out the *Stars* of the Firmament, and with great Care and Induſtry they have digeſted them into Catalogues, which they have delivered down to Poſterity. Theſe Catalogues have been much increaſed and Corrected by our Modern *Aſtronomers*, and now they not only comprehend the *Stars* viſible by the naked Eye, but alſo many that are not to be obſerved or ſeen without a Teleſcope.

Hipparchus *firſt compoſed a Catalogue of the* Stars.

HIPPARCHUS the *Rhodian* about 120 Years before the Birth of *Chriſt*, was the Firſt among the *Greeks* who reduced the *Stars* into a Catalogue. *Daring*, according to *Pliny*, *to undertake a Thing, which ſeemed to ſurpaſs the Power of a Divinity, that is to Number the* Stars *for Poſterity, and reduce them to Rule; having contrived Inſtruments by which he marked the Place and Magnitude of each* Star. *So that by this Means we can eaſily diſcover, not only whither any of the* Stars *periſh, and others grow up; but alſo whither they move, and what is their Courſe, and alſo if they grow bigger, or wax leſs; by which means he has given to Poſterity the Poſſeſſion of the Heavens, if any of them have Subtilty enough to Comprehend them.*

HIPPARCHUS from his own proper Obſervations, and thoſe of the Antient *Aſtronomers* who lived before him, inſerted into his Catalogue 1022 *Stars*, and annexed to each of them their proper Longitude, and Latitude, which they had at that time. *Ptolemy* enlarged *Hipparchus*'s Catalogue only with four *Stars*, numbring 1026. And after *Ptolemy*, *Ulug Beighi*, the Grandſon of the Great *Tamerlain*, obſerved again the *Stars*, and reduced 1017 of them into a Catalogue. In the 16th Century, and that which followed, *Aſtronomy* was courted by many Admirers and Suiters; among whom we may chiefly reckon *Regiomontanus*, and *Copernicus*. But the Noble *Daniſh Aſtronomer Tycho Brahe*, in a-

Ulug Beighi *made a new Catalogue.*

As likewiſe Tycho Brahe.

dorning and perfecting this Science, did far ſurpaſs the Labours of all that went before him; who procured very large and exquiſitely well contrived Inſtruments for obſerving the Heavens, and particularly he determined the Places of 777 *fixed Stars*, and reduced them into a Catalogue, their Places being all Calculated from his own proper Obſervations. *Kepler* indeed in his *Rudolphin* Tables gives us a Catalogue of the *Stars*, he calls *Tychonick*, in which he has put down 1163 *Stars*; but all of them except the 777 obſerved by *Tycho*, were taken partly from *Ptolemy*, and partly from other Authors. For *Tycho* in his own Catalogue ſets down no *Star* which he had not obſerved himſelf, by his own Inſtruments, and Calculated the Place from his proper Obſervations.

The Prince of Heſs.

ABOUT the ſame Time with *Tycho* lived *William* Prince of *Heſs*, who likewiſe obſerved the *Stars*: He had two *Mathematicians* to aſſiſt him, *Rothmannus* and *Byrgius*, with whom, by thirty Years continued Labour, he computed the Places of 400 *Stars* all founded on their own Obſervations, and inſerted them in a Catalogue.

Ricciolus.

THE Jeſuite *Ricciolus* inriched the Catalogue of *Kepler* with 305 *Stars*, by which means their Number was increaſed to 1468; but this Catalogue was not founded on his own Obſervations, for he and his Companion *Grimaldi*, did not take the Places of above 101 *Stars* with their own Inſtruments; and he took all the reſt from *Tycho*, *Kepler*, and other Authors: But it is Surprizing that *Ricciolus* ſhould inſert in his Catalogue ſeveral *Stars* which were plainly viſible in *Tycho*'s time, and duly obſerved by him, but which in *Riccioli*'s Days had vaniſhed, and were not to be ſeen; and yet they are preſerved in his Catalogue, as if he himſelf had then obſerved them.

BARTSCHIVS in his Book about the four Foot Globe Publiſhed at *Strasburgh* in 1635 in *4to*, tells us that *Bayerus* had deſcribed in his *Vranometria* the Places of 1725 *Stars*, and he alſo boaſts that he himſelf had painted in his Globe 1762 *Stars*, but he does not tell us by whom, or in what Year, they were obſerved.

THE *Stars* near the *Antarctick Pole*, not to be ſeen in our Climate, were firſt accurately obſerved by my Collegue Dr. *Edmund Halley*, who being animated with a great Love of this Siderial Science, undertook a long, and no leſs dangerous Voyage to the Iſland of St. *Helena*, that he might there take the Poſition of the *Stars* which are within the *Antarctick Circle*; and he Publiſhed a Catalogue of 373 of them, whoſe Places he adapted to the end of the Year 1677.

Dr. Halley *firſt exactly obſerved the* Southern Stars.

THE illuſtrious *John Hevelius* of *Dantzig*, a Man of prodigious Induſtry, and unwearied Diligence, being well furniſhed with very exact Inſtruments, and with all the Tools that are proper for an *Aſtronomer*; did again aſſault the *Stars* with his Inſtruments, and computed the Places of 1553 of them from his own proper Obſervations, and ſo he compoſed a new Catalogue which contained 1888, *viz.* 950 known to the Antients, and which were to be ſeen at *Dantzig*; 603 new ones which no one before had ever rightly obſerved, and to them he joined 335 others round the *Antarctick Pole*, taken out of Dr. *Halley*'s, Catalogue which lye always hid under the *Horizon* of *Dantzig*.

Hevelius.

BUT the largeſt and moſt compleat Catalogue of the *Stars*, is ſhortly to be expected from the Labours of that moſt excellent Obſerver Mr. *John Flamſteed*, late Royal Profeſſor of *Aſtronomy* at *Greenwich*; the Number of *Stars* inſerted in this Catalogue reach to 3000. And as *Hevelius* doubled by his Obſervations the Number of *Stars* obſerved by *Tycho*: So our *Britiſh Aſtronomer* has as far outdone *Hevelius*, having by his Obſervations doubled the *Stars* that were obſerved by him: We are ſo much indebted to this *Aſtronomer* for the increaſe of the Knowledge we have of the *Celeſtial Bodies*, that there is not the leaſt *Star* in the Heavens to be ſeen, whoſe Place and Situation is not

Mr. Flamſteed *has made the moſt Copious and moſt exact Catalogue.*

better known, than the Poſition of many Cities thro' which Travellers do daily paſs. Nor is it any wonder that the *Aſtronomers* ſhould take ſo much Pains, and ſo obſtinately watch the *fixed Stars*, to determine their Places; for without the exact ſetling of their Poſitions and Places, they could never have found out the ways of the *Planets*, nor have deſcribed their Orbits: For it is upon the Obſervations of the *fixed Stars*, as upon immoveable Pillars, that the whole Science of *Aſtronomy* is erected, and by them it is ſuſtained.

The Number of the Stars.

OF the 3000 *Stars* inſerted in Mr. *Flamſteed*'s Catalogue, there are many that cannot be ſeen without a Teleſcope, ſo that it is ſeldom that even a very good Eye can reckon more than 100 together in the Heavens: This will certainly ſurpriſe a great many Perſons, for in the Winter, in a clear Night, without *Moon-ſhine*, at firſt ſight they ſeem to be innumerable. But this Appearance is only a deception of our Sight, ariſing from their vehement and ſtrong Twinkling or Scintillation, while we look upon them confuſedly, and without reducing them to any Order; but he who will diſtinctly view them, will find not one but what are Obſerved by the *Aſtronomers*, and inſerted in their Catalogues: And if any one will take a Globe of the larger ſize, and compare it with the Heavens, he will rarely find any *Star* in the Heavens, that is not marked upon the Surface of that Globe.

IN the mean time I muſt acknowledge that the Number of the *Stars* is really vaſtly great, and almoſt infinite; for whoever will view the *Stars* with a good Teleſcope, will find every where a prodigious Number of them altogether indiſcernable by the naked Eye, eſpecially in the *Milky-way*; where they are ſo thick, that tho' they cannot be ſeen ſeparately, yet they give that Region of the Heavens where they are placed, a Luſtre above all the reſt.

Many Stars imperceptible to the naked Eye.

THE Famous Dr. *Hook* Profeſſor of *Geometry* in *Greſham College*, directing his twelve-Foot Teleſcope to the *Pleiades* or the ſeven *Stars*, tho' there are now only but ſix to be ſeen with the naked Eye, did in that ſmall compaſs count 78 *Stars*; and making uſe of longer and more perfect Teleſcopes, he diſcovered a great many more of very different Magnitudes: See his *Micrography*, pag. 241. *Antonius Maria de Reita* in his Book which he calls *Radius Sidereomyſticus*, pag. 197 affirms, that he has numbered in the ſingle Conſtellation of *Orion* 2000 *Stars*.

The matter of the Heavens is corruptible and changeable.

FROM what we have ſaid, in the preceding Lecture, it plainly appears, how falſe and ill founded, was the Notions of the Antient *Philoſophers*, who having too favourable an Opinion of the Heavenly Regions, granted them ſome Priviledges without any reaſonable ground: For they affirmed that the Heavens were incapable of any Change, that the Celeſtial matter was of a different kind from any we have in our *Earth*, and that its firmneſs did far exceed that of the moſt durable Diamond, for that is ſtill Corruptible and may be changed into other ſorts of Matter, and undergo ſeveral Tranſmutations: But the Form of the Heavenly matter, according to them, is permanent and Eternal. We have ſeen in the *Sun* and *Planets* that there are frequently new Bodies produced and generated; others again are corrupted and periſh, and the Faces of the *Planets* undergo many Changes. Thoſe *Alterations* are not peculiar to our *Earth*, or our Planetary Syſtem; the Principle of Generation and Corruption is much further diffuſed, it reaches even the moſt diſtant *fixed Stars*, and all the Bodies of the Univerſe are under its Dominion; there is nothing but our Mind and our Spiritual part that are exempted from its Juriſdiction: For the Heavenly Bodies as well as the Terreſtrial are changeable and periſh. Several *Stars* which were obſerved by the Antients, are now no more to be ſeen, but are deſtroyed, and we have known ſome new ones come in the Heavens unknown to them; which likewiſe in due time will vaniſh, and diſappear: There are alſo ſome *Stars* which for a Time are extinguiſhed, and become inviſible, but after a certain Period they reaſſume their former Luſtre. Of theſe *Stars* the moſt remarkable is that which is in the Neck of the *Whale*, which for eight or nine Months of the Year withdraws it ſelf from our Sight, and for the other three or four Months is conſtantly changing its Luſtre and Bigneſs. It is probable that the greateſt Part of the Surface of this *Star* is covered with Spots and dark Bodies, ſome Part thereof remaining lucid; and while it turns about its *Axis*, does ſometimes ſhow its bright Part, ſometimes it turns its dark ſide to us: But the very Spots themſelves of this *Star* are liable to Changes, for it does not every Year appear with the ſame Luſtre; ſometimes it reſembles a *Star* of the ſecond Magnitude, in other Years it can ſcarcely be reckoned among *Stars* of the third Order; nor are the Times of its viſiting us, always of the ſame duration; for in ſome Years after three Months it takes its leave of us, in others we enjoy its Light for the ſpace of four Months; nor does its increaſe or decreaſe always anſwer the difference of Times.

Some Stars *vaniſh or periſh, and again appear.*

MOREOVER we are aſſured from the Obſervations of *Aſtronomers*, that ſome *Stars* have been obſerved which never were before, and for a certain time they have diſtinguiſhed them by their *ſuperlative Luſtre*; but afterwards decreaſing, they by degrees vaniſhed and were no more to be ſeen. One of theſe *Stars* being firſt ſeen and obſerved by *Hipparchus*, the chief of the *Aſtronomers* of the Antients, ſet him upon compoſing a Catalogue of the *fixed Stars*, that Poſterity might by it learn whether any of the *Stars* periſh, and others are produced afreſh.

New Stars.

AFTER ſeveral Ages, another new *Star* appeared to *Tycho*, and the *Aſtronomers* that were Contemporary with him; which juſt like the new *Star* in *Hipparchus*'s time, induced him likewiſe to make a new Catalogue of the *fixed Stars.* This *Star* made its Appearance in the Conſtellation *Caſſiopeia,* and was firſt obſerved about the middle of *November* 1572, and never changed its Place all the time it was viſible, which was for the ſpace of ſixteen Months: But yet by degrees it diminiſhed, and at laſt became inviſible. Its Magnitude exceeded that of *Sirius* or *Lyra,* which are the brighteſt of the *fixed Stars,* and even vied with *Venus* when ſhe is neareſt to us: So that ſometimes it could be ſeen in fair Day light, or Sun ſhine; but at laſt it continually loſt ſomething of its Splendor 'till it quite diſappeared, and it has never been ſeen ſince. *Leovicius,* from the Hiſtories of thoſe Times, tells us, that in the Time of the Emperor *Otho,* about the Year 945, a new *Star* appeared in *Caſſiopeia,* juſt ſuch a one as was ſeen in his Time in the Year 1572. And he brings us another Antient Obſervation, that there was likewiſe ſeen in the *Northern* Region of the Heavens, near the Conſtellation *Caſſiopeia,* in the Year 1264, an eminently bright *Star,* which kept it ſelf in the ſame Place, and had no proper Motion. It is probable that theſe two *Stars* might have been the ſame with that which was ſeen by *Tycho,* and that in about 150 Years the ſame *Star* may again make its Appearance.

IN the Year 1600 and the following, *Kepler* obſerved another new *Star* in the *Swan*'s Breaſt, which remained viſible for many Years; and in *Hevelius*'s time looked like a *Star* of the third Magnitude, but at laſt became inviſible from the Year 1660 'till the Year 1666, when it was again obſerved by *Hevelius* as a *Star* of the ſixth Magnitude, juſt in the ſame Place it was at firſt obſerved in; where it now appears.

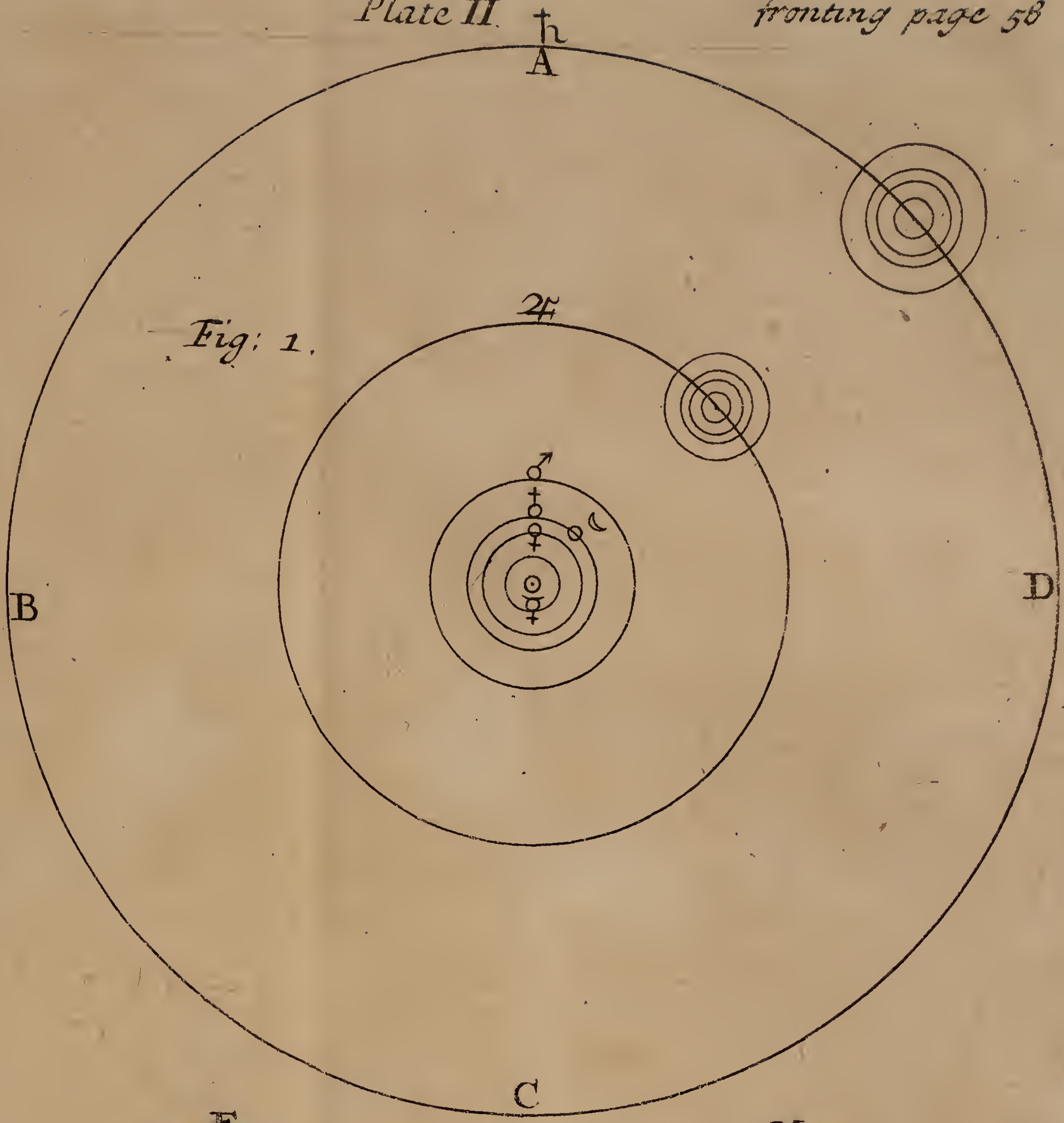
WE are aſſured by the Catalogues of the *fixed Stars,* that many *Stars* have been obſerved by the Antients, and ſome even by *Tycho,* which are now become Inviſible, and particularly in the *Pleiades* or ſeven *Stars;* there was formerly counted ed Seven, but now we can reckon but Six, and ſo it was in *Ovid*'s time, who in his third Book of the *Faſti* has this Verſe

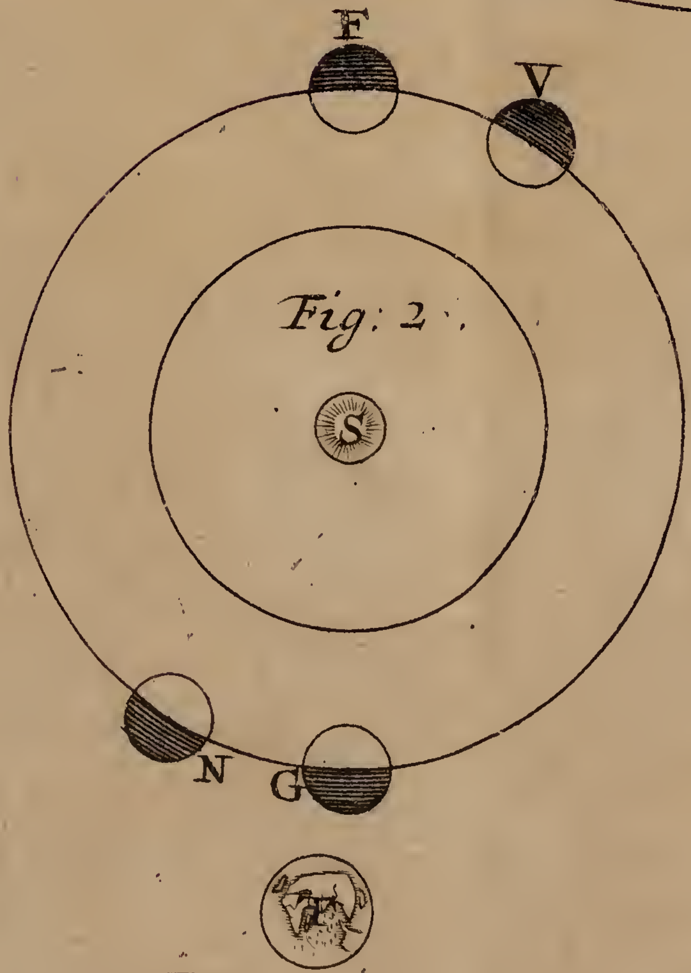
Quæ ſeptem dici, ſex tamen eſſe ſolent.

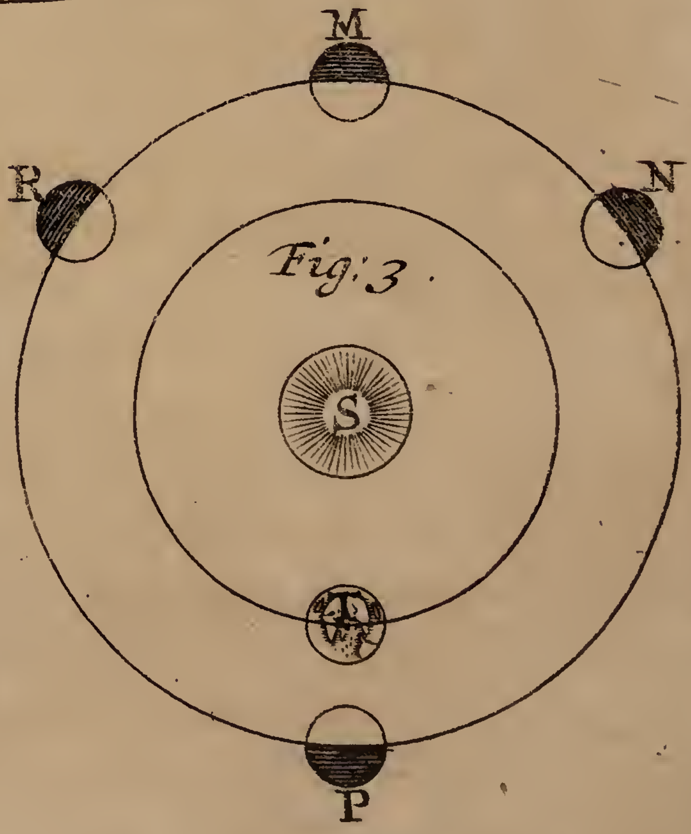
THE celebrated Mr. *Montanere*, Profeſſor of *Mathematicks* of the Univerſity of *Bononia*, in his Letter written to the ROYAL SOCIETY dated *April* 30, 1670 has theſe Words. "There "are now wanting in the Heavens two *Stars* of "the ſecond Magnitude, in the Stern of the Ship "*Argo*, and its Yard; *Bayerus* marked them with "the Letters β and γ. I and others obſerved "them in the Year 1664, upon the Occaſion of "the Comet that appeared that Year: When "they diſappeared firſt I know not, only I am "ſure, that in the Year 1668, upon the 10th of "*April*, there was not the leaſt glimpſe of them "to be ſeen; and yet the reſt about them, even "of the third and fourth Magnitudes, remained "the ſame. I have obſerved many more Changes "among the *fixed Stars*, even to the Number of a "Hundred, tho' none of them are ſo great as thoſe "I have ſhewed.

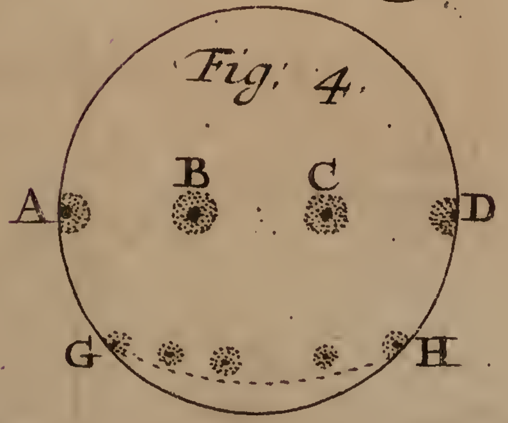
IT is no ways improbable that theſe *Stars* loſt their Brightneſs by a prodigious Number of Spots, which intirely covered and as it were overwhelmed them. In what diſmal condition muſt their *Planets* remain, who have nothing but the dim and twinkling Rays of the *fixed Stars* to enlighten them.

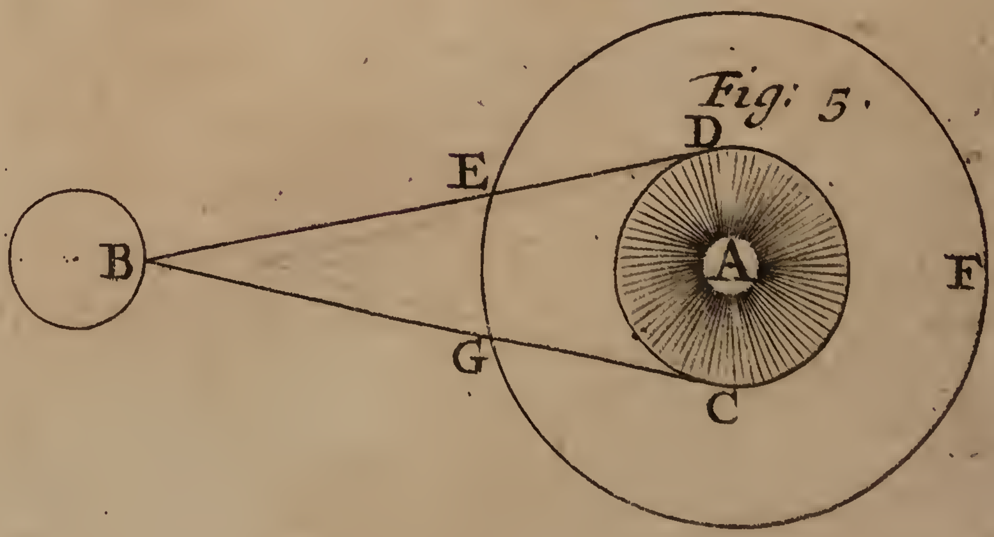
Plate II. *fronting page 58*











LECTURE VII.

Of the Motion of the Earth *round the* Sun: *And alſo about her own* Axis, *whereby the Apparent Motion of the* Sun *and Heavens are explained.*

HAVING taken a Curſory view of the Univerſe, and explained thoſe Things which we have diſcovered concerning the *fixed Stars,* we will now come to conſider more accurately our own Solar Syſtem; for our *Aſtronomy* is chiefly concerned about the Motions of the Bodies that are contained in it, and about the Appearances or *Phænomena* that ariſe from thoſe Motions.

We are to begin with the Motion of the Earth.

AND firſt it is reaſonable that we ſhould begin from the Motion of the *Earth,* which is our own Seat and Habitation, that is from our own Motion; ſince we are to be the Spectators of all the Appearances which are here to be explained, and particularly becauſe from our Motion ariſes the Apparent Motion of the *Sun,* which if not firſt known, the Appearances and Motions of the *Planets* can neither be explained or computed.

The Sun *in the Center of our Syſtem.*

The Earth *turns round the* Sun.

WE have in the preceding Lectures demonſtrated that the *Sun,* which is by far the biggeſt and moſt noble Body of the Univerſe, does poſſeſs himſelf of the Center, from whence he every way diffuſeth upon all the *Planets* his enlivening Beams and Warmth; and that they as it were Dance round him at different Diſtances and Periods. The *Earth* which we inhabit is to be reckoned as one of them, who goes round the *Sun* in the ſpace of a Year; and at the ſame time turns round her own *Axis* every twenty four Hours. Now ſince the Diſtance of the *fixed Stars* is immenſly great, in compariſon of the Diſtance of the *Earth* from the *Sun*, the Starry Firmament will have the ſame Face, and there will be the ſame Situation, Order, and Magnitude of the *Stars*, whether they be viewed from the *Sun*, or from the *Earth*: But ſince all diſtant Bodies appear as if they were in the Heavens, a Spectator in the *Sun* will obſerve the *Earth* to deſcribe a Circle in the Starry Firmament; and becauſe the Plane of the *Earth*'s Orbit paſſes thro' the *Sun*, the Circle which the *Earth* deſcribes will appear to be a great Circle in the Heavens.

The ſame Order and Poſition of the Stars *is ſeen from the* Sun *and* Earth.

The Motion of the Earth *ſeen from the* Sun. Plate III. Fig. 1.

LET S repreſent the *Sun*, A B C D the Orbit of the *Earth*, in which the *Earth* is carried from the *Weſt* to the *Eaſt* in the compaſs of a Year. A Spectator in S looking upon the *Earth* at A, will referr it to the Star ♈, as if it were in the ſame point of Space with that *Star*: But when the *Earth* is brought to B, the Spectator in S will ſee the *Earth* in the Heavens juſt by the Star ♋; when the *Earth* is gone forward to C, it will be ſeen from the *Sun* in ♎; and when it is come to D, it will appear in ♑; and when it is returned to A, having finiſhed its Period, it will be ſeen again in ♈.

The Ecliptick *and its Diviſion into 12 Parts or Signs.*

HENCE if the Plane of the *Earth*'s Orbit be imagined extended to the Heavens, as far as the *fixed Stars*, it will cut the Starry Firmament, or the concave ſpherical Surface, in which all the *Stars* appear, in that very Circle in which a Spectator in the *Sun* would ſee the *Earth* to revolve every Year: This Circle is called the *Ecliptick*, and is divided by the *Aſtronomers* into twelve equal Parts, which are called Signs; each of them takes its Name from that Conſtellation, which, at the time the Names were impoſed, was ſituated near the Portion of the *Ecliptick* it denominates. Theſe Signs or Portions are the *Ram* ♈, the *Bull* ♉, the *Twins* ♊, the *Crab* ♋, the *Lyon* ♌, the *Virgin* ♍, the *Ballance* ♎, the *Scor-*

pion ♏, the *Archer* ♐, the *Goat* ♑, the *Water Bearer* ♒, and the *Fiſhes* ♓.

The Apparent Motion of the Sun *ſeen from the* Earth.

LET us now bring our Spectator from the *Sun* to the *Earth*, and let him be carried by it round the *Sun*, and let us imagine that the *Earth* is in C: A Spectator ſees the ſame Face of the Heavens, and the very ſame Conſtellations, as we have ſaid he did before while he was in the *Sun*; the only difference will be, that as before he imagined the *Earth* in the Heavens, and the *Sun* in the Center, he will now ſuppoſe the *Sun* to be in the Heavens, and himſelf with the *Earth* in the Center, it being really the Center of his own view. Therefore the *Earth* being in C, the Spectator will ſee the *Sun* at the Star ♈; and the Spectator being carried along with the *Earth*, and participating of the Annual Motion, which is common to them both, he will obſerve all the Parts of the *Earth*, and all the Bodies fixed on its Surface to keep the ſame Poſition in regard to one another, and to his own Eye, and always to remain at the ſame Diſtance from him; and therefore he cannot by his Eye perceive either his own Motion, nor that of the *Earth*. But looking to the *Sun*, and obſerving him, when the *Earth* comes to D, he will ſee the *Sun* at the *Star* ♋, and will perceive that he has changed his Place among the *Stars*, and has moved from ♈, by ♉, ♊, to ♋: And while the *Earth* goes on in its Progreſs, and goes to A, the *Sun* will be ſeen from thence to have moved thro' the Signs ♋, ♌, and ♍: and Again, while the *Earth* deſcribes the Semicircle A B C, the *Sun* will appear to have moved, in the concave Surface of the Heavens, thro' the ſix Signs ♎, ♏, ♐, ♑, ♒, ♓. And therefore an Inhabitant of the *Earth*, obſerves the *Sun*, which is really immoveable, to go thro' the ſame Circle in the Heavens, and in the ſame Space of time, that a Spectator in the *Sun* would ſee the *Earth* deſcribe.

HENCE ariſes that Apparent Motion of the *Sun*, by which it is obſerved to creep every Day by little and little towards the *Eaſtern Stars*; ſo that if any *Star* near the Ecliptick does at any time riſe with the *Sun*, after ſome few Days the *Sun* will be got more to the *Eaſt* of the *Star*, and the *Star* will riſe before the *Sun*, and will likewiſe ſet before him. So likewiſe a *Star* which is *Eaſtward* of the *Sun* and is ſeen after the *Sun* ſets, at a conſiderable Diſtance from him, in the Space of ſome few Days will ſet with the *Sun*, and will no more be ſeen, after the *Sun* goes down. This Motion of the *Sun* which is contrary to the apparent Diurnal Revolution of the Heavens from *Eaſt* to *Weſt*, was eſteemed to be real by the Followers of *Ptolemy*, who maintained that the *Sun* and all the *Stars* had two Motions, contrary to one another, the one common with the Heavens from *Eaſt* to *Weſt*, in the Space of 24 Hours; the other proper, and peculiar to each, and was from the *Weſt* to the *Eaſt*; which Courſe the *Sun* finiſhed in the Space of a Year. But we have ſhewed that there is no ſuch real Motion in the *Sun*, and that it is only Apparent, ariſing from the Motion of the *Earth*.

The Sun *will have juſt ſuch Motions when it is obſerved from other* Planets.

THE Inhabitants of all the other *Planets* will obſerve juſt ſuch Motions in the *Sun*, and for the very ſame reaſons that we do in our *Earth*: And the *Sun* will be ſeen from every *Planet*, to deſcribe the ſame Circle, and in the ſame ſpace of Time, that a Spectator in the *Sun* would obſerve the *Planet* to do. For Example: An Inhabitant of *Jupiter* would think that the *Sun* turns round him, and would ſee him deſcribe a Circle in the Heavens, in the ſpace of twelve Years; that Circle would not be the ſame with our Ecliptick, and the Motion of the *Sun* would not be thro' the ſame *Stars*, which he appears to us to paſs by. And upon the ſame Account the *Sun* ſeen from *Saturn* will appear to move in another Circle diſtinct from either of the former, and will not ſeem to finiſh his Period in leſs time than 30 Years. Since therefore it is impoſſible that the *Sun* can have all theſe Motions really in it ſelf, and there can be no reaſon ſhewn why any one of them ſhould belong really to the *Sun* more than the reſt, we may ſafely affirm that there are none of them real, but that they are all Apparent, and ariſe from the Motions of the reſpective *Planets.*

The Gyration of the Earth *round its* Axis.

BESIDES this Annual Circulation of the *Earth*, it has alſo a *vertiginous Motion* round his *Axis*, from the *Weſt* to the *Eaſt*, in twenty four Hours: The two Points in which the *Axis* meets with the Surface of the *Earth* are called the *Poles* of the *Earth*, and if this *Axis* be indefinitely produced to the Heavens both ways, it will mark in the Heavens two Points, which are called the *Poles* of the Heavens: Every Point on the Surface of the *Earth*, except the *Poles* will deſcribe the Circumference of a Circle bigger or leſs, according as it is further diſtant or nearer to one of the *Poles.* The *Poles* are the only two Points which have no Verticity: This plainly follows from the Nature of a Vertiginous Motion. Any place on the Surface of the *Earth*, which is equally diſtant from both the *Poles*, deſcribes by its Rotation a great Circle, which is called the *Æquator* of the *Earth*, or the *Æquinoctial Circle*; and the reſt deſcribed by Points nearer to one of the *Poles*, are leſſer Circles and are called Parallels.

The Poles.

The Æquator, *or* Æquinoctial *and Parallels.*

IF we imagine a Plane to paſs over that Point of the *Earth*'s Surface on which the Spectator ſtands, and to touch the Globe of the *Earth* there; this Plane extended as far as the Heavens, will divide the Heavens into two Parts, and its Section with the Heavens will make a Circle, which is called the *Horizon*; and it will ſeparate or diſtinguiſh the viſible and open part of the Heavens, from that which is inviſible, and which the Opakeneſs and Convexity of the Earth hides from us. This *Horizon* which we have deſcribed is properly the Senſible *Horizon*: The Rational

The Horizon.

Plate III. Fig. 2.

The Senſible and Rational Horizon.

zon being a diſtinct Circle, which paſſes thro' the Center of the *Earth*, and is Parallel to the ſenſible which touches the Surface. But theſe two Circles, tho' they are diſtant from one another by the Semidiameter of the *Earth*, yet in the Heavens they may be reckoned as coinciding; for that Semidiameter is but a Point, in compariſon of the Diſtance of the Heavens.

The Rotation of the Earth *produces an Apparent Revolution of the Heavens round the* Earth.

SINCE the *Earth* turns round its *Axis*, the Spectator ſtanding on its Surface, muſt likewiſe turn round with it the ſame way, that is towards the *Eaſt*: And therefore all the Bodies in the Heavens, which are placed in the *Eaſt*, and were not to be ſeen by reaſon the Plane of the *Horizon* was above them, will become Viſible, when by the Rotation this Plane ſubſides, and comes under them: So likewiſe the oppoſite part of this Plane towards the *Weſt*, riſing above the *Stars*, will hide them from the ſight of the Spectator, and all the *Stars* in the *Weſt* will become Inviſible: Hence it is the *Stars* of the *Eaſtern* ſide of the *Horizon* will appear to riſe above the *Horizon*, becauſe the *Horizon* deſcends below them, and the *Stars* on the *Weſtern* ſide will appear to ſet or go below the *Horizon*, becauſe the *Horizon* does really get above them. Hence ariſes that Apparent Motion of all the Bodies of the Univerſe that do not adhere to the *Earth*, wherewith the whole Starry Firmament, and every Point of the Heavens ſeems to revolve about the *Earth* from *Eaſt* to *Weſt*; every Point deſcribing a greater or a leſſer Circle, as it is more remote or nearer to one of the Celeſtial *Poles*: And theſe Celeſtial *Poles* which are made by the Production of the *Earth*'s *Axis* to the Heavens, are the only Points in the Heavens, which appear to be immoveable.

ALTHO' every place on the Surface of the Terraqueous Globe, is illuſtrated by all the *Stars* which are above the *Horizon* of that Place, or rather when the *Horizon* is under the *Stars*; yet the Illumination made by the *Sun* is ſo great, and the Reflection of its Light by the Atmoſphere ſo ſtrong, that the *Sun* when he is above the *Horizon*, does with his Preſence quite extinguiſh the faint Light of the *fixed Stars*, and produces Day: When the *Sun* withdraws himſelf, and goes below our *Horizon*, or more properly when our *Horizon* gets above the *Sun*, he then gives leave to the *Stars* to Shine and appear, at which time it is Night. Now ſince the *Earth* is an opake Spherical Body, at a great Diſtance from the *Sun*, one half of it will always be illuminated by the *Sun*, while the other half remains in Darkneſs: And the Circle which diſtinguiſhes the illuminated Face of the *Earth* from the Dark ſide, is called the Circle of the Interſection of Light and Shadow; a Line drawn from the Center of the *Sun*, to the Center of the *Earth*, is always Perpendicular to the Plane of this Circle.

Whence Day-Light.

Whence Night.

The Circle bounding Light and Darkneſs.

IF the *Axis* of the *Earth* had been placed in a Poſition Perpendicular to the Plane of the Ecliptick, then in that caſe the Plane of the *Earth*'s Æquator had coincided with the Plane of the Ecliptick, or the Plane of the *Earth*'s Orbit; and the Circle bounding Light and Darkneſs, would have always paſſed thro' the *Poles* of the *Earth*, and cut the Æquator and all its Parallels into equal Portions: And therefore in that caſe, the *Sun* and all the *Stars* would have remained as long above the *Horizon*, as they would have lain hid under it, and the Days would have been conſtantly equal to the Nights. But now, as the Caſe is, the *Axis* of the *Earth* is not Perpendicular to the Plane of the Ecliptick, but is inclined to that Plane, and makes with it an Angle of 66½ Degrees; and therefore the Plane of the *Earth*'s Æquator cannot coincide with the Plane of the *Ecliptick*, but theſe two Planes make with one another an Angle of 23½ Degrees.

The Axis of the Earth *is not Perpendicular to the Plane of the Ecliptick.*

IF the Plane of the *Earth*'s Æquator be imagined to be produced as far as the *fixed Stars*, it will there make a Circle which is called the Celeſtial Æquinoctial; which is exactly over the

The Æquinoctial of the Heavens.

Terre-

Terreſtial Æquinoctial: This Circle makes with the Ecliptick in the Heavens, an Angle likewiſe of 23½ Degrees.

The Parallelism of the Earth's Axis.

THE *Earth* in its Revolution round the *Sun* does in ſuch a manner proceed in its Orbit, that it keeps its *Axis* Parallel to it ſelf; that is, if a Line be drawn Parallel to the *Axis* while it is in any one Poſition, the *Axis* in all other Poſitions or Parts of the Orbit will always be Parallel to that ſame Line, and it will never change its Direction, but always look towards the ſame Point of the Heavens: And this will neceſſarily be, if the *Earth* have no other Motion but that round the *Sun*, and the other round its own *Axis*. For ſuppoſe any Body, whoſe Center is carried in the Line A B, and in A we ſhould Mark any Diameter C D, which is inclined in any Angle to the Line A B; if this Body have no other but a progreſſive Motion in the Line A B, when it comes to the Point B, the Diameter C D will be in the Situation *c d*, and its Poſition will be Parallel to the former Poſition C D: Now if there ſhould be impreſſed upon this Body a Rotation round C D as an *Axis*, all the Diameters of the Body will conſtantly change their Poſition by this Rotation, except the *Axis* which will remain is its former State: The Points in the *Axis* being the only Points in the Body which have no Rotation. But this *Axis*, as was ſhewed, did before the Rotation always preſerve a Poſition Parallel to it ſelf, therefore after the Rotation is impreſſed upon the Body, the *Axis* will ſtill keep Parallel to its ſelf.

Plate III. Fig. 3.

HENCE it is evident that there is no need of a third Motion for the *Earth*, as ſome have imagined it muſt have, to make it keep its *Axis* Parallel to its ſelf: For to this effect there is nothing more required, that than it ſhould have only the former two, with which alone it will neceſſarily keep its *Axis* Parallel to it ſelf.

Lecture VII.

SINCE the Plane of the Æquator does not coincide with the Plane of the Ecliptick, theſe two Planes muſt cut one another in a right Line, and while the *Earth* turns round the *Sun*, the common Section of theſe two Planes will likewiſe always remain Parallel to its ſelf; for the ſame reaſon as we ſhewed in the Poſition of the *Earth*'s *Axis*: And therefore this Section or Line, in which the Planes cut one another, will always be directed towards two oppoſite Points of the Ecliptick, and will always look to the ſame Points of the Univerſe.

The Æquinoctial Colure.

And the Solſtitial Colure.

A great Circle in the Heavens paſſing thro' the two Celeſtial *Poles*, and the common Section of the Æquator and the Ecliptick is called the *Æquinoctial Colure*: An other Circle cutting the former in the *Poles* at right Angles, is called the *Solſtitial Colure*, which paſſes thro' the Points where the Æquator and Ecliptick are at the greateſt Diſtance from one another, and cuts likewiſe both theſe Circles at right Angles, and therefore does likewiſe paſs thro' the *Poles* of the Ecliptick, or that Point which is every where equally diſtant from the Ecliptick. The four Points in which theſe two *Colures* interſect the Ecliptick, are called the four *Cardinal Points*, becauſe when the *Sun* is ſeen in them, he determines the four Seaſons of the Year. The two Interſections of the *Æquinoctial Colure* with the Ecliptick, are called the *Æquinoctial Points*; the other two being the Interſections of the *Solſtitial Colure* with the Ecliptick, are called the *Solſtitial Points*.

The Cardinal Points.

Plate III. Fig. 4.

SUPPOSE now the Eye of a Spectator to look from afar, obliquely upon the Orbit of the *Earth*; it will then appear or have a Repreſentation of an Oval figure, according to the Rules of Perſpective, and in the middle of this Oval the *Sun* will keep. Thro' the Center of the *Sun* S, draw the right Line ♈ S ♎ parallel to the common Section of the Æquator and the Ecliptick, which will meet with the Ecliptick in two Points ♈, ♎: And when the *Earth* ſeen from the *Sun* is in either

The different illumination of the Parallels, according to the Place of the Earth *in the* Ecliptick.

The Appearances when the Earth *is in* Libra, *and the* Sun *is ſeen in* Aries.

of theſe Points, the right Line S ♈ or S ♎, which joins the Center of the *Earth* and *Sun*, will coincide with the common Section of the Æquator and Ecliptick, and will then be Perpendicular to the *Axis* of the *Earth* or of the Æquator, becauſe it is in the Plane of the Æquator: But the ſame Line is alſo Perpendicular to the Circle which bounds the Light and Darkneſs, and therefore the *Axis* of the *Earth* will be in the Plane of that Circle, which will therefore paſs thro' the *Poles* of the *Earth*, and will cut the Æquator and all its Parallels into equal Parts. When the *Earth* therefore is in the beginning of ♎, the *Sun* will be ſeen in ♈, in the common Section of the Æquator and the Ecliptick; and therefore it will appear in the Celeſtial Æquinoctial, and will not be ſeen to decline to either of the *Poles*; but being exactly in the middle between both, it will then by its Apparent diurnal Revolution deſcribe the Celeſtial Æquinoctial. In this Poſition of the *Earth*, the *Sun* will exactly illuminate the *Earth* from *Pole* to *Pole*, and as we ſaid the Circle bounding Light and Darkneſs, will cut the Parallels exactly into equal Parts, and every Point of the *Earth* being carried round by the vertiginous Motion, will remain as long in the obſcure ſide, as it was in the light or illuminated Portion of the *Earth*'s Surface: And therefore at that time thro' the whole Globe of the *Earth*, the Day will be equal to the Night: From hence the Circle which that Day the *Sun* ſeems to deſcribe in the Heavens, has obtained the Name of *Æquinoctial*.

The Appearances when the Earth *is in* Capricorn.

THE *Earth* in its Annual Motion going by degrees thro' ♏ and ♐ towards ♑, and the common Section of the Æquator and the Ecliptick remaining always Parallel to its ſelf, it will no longer paſs thro' the Body of the *Sun*, but in ♑ it makes a right Angle with the Line S P, which joins the Centers of the *Sun* and *Earth*: And becauſe the Line S P is not in the Plane of the Æquator, but in that of the Ecliptick; the Angle B P S, which the *Axis* of the *Earth* makes with it, will not now be a Right Angle, but Oblique; theſe two Lines making an Angle of 66½ Degrees, which is the ſame with the Inclination of the *Axis* to the Plane of the Ecliptick. Let the Angle S P L be a Right Angle, and the Circle bounding Light and Darkneſs will paſs thro' the Point L; and then the Arch B L, or the Angle B P L, will be 23½ Degrees, that is equal to the Complement of the Angle B P S to a right Angle.

LET the Angle BPE be a right Angle, and then the Line P E will be in the Plane of the Æquator: Therefore becauſe the Arches B E and L T are equal, each of them being Quadrants; if the common Arch B T be taken away, there will remain T E equal to L B equal to 23½ Degrees. Take E M equal to E T, and thro' the Points M and T, deſcribe two Parallel Circles T C, M N; the one is called the *Tropick* of *Cancer* ♋, the other the *Tropick* of *Capricorn* ♑. And the *Earth* being in this Situation, the *Sun* will ſhine perpendicularly upon the Point T, and then it will ſeem to approach the neareſt that it can come to the *North Pole*. And the Circle which, by the Apparent diurnal Revolution of the Heavens, the *Sun* ſeems to deſcribe, will be directly over the Circle T C in the *Earth*, which Circle is therefore called the Celeſtial Tropick of *Cancer*: Now upon the account of the Revolution of the *Earth* round its *fixed Axis*, all the Points of the Parallel T C will in their turns paſs by the Point T, and will be directly under the *Sun*; and therefore the *Sun* will be vertical to all the Inhabitants that are under the Tropick of ♋, when he comes to their Meridians. While the *Earth* is in this Poſition, it is manifeſt that the Circle which bounds Light and Darkneſs reaches beyond the *North Pole* B to L; but towards the *South* it falls ſhort of the *South Pole* A, and reaches no further than F. Thro' L and F let two Parallels to the Æquator be

The two Tropicks.

deſcribed: Theſe two Circles are called the *Polar Circles*; this is called the *Arctick Polar*, the other the *Antarctick*. And while the *Earth* is in P, all that Tract of it which is included within the *Polar* Circle K L continues in the Light, notwithſtanding the conſtant Revolution round the *Axis*; and the Inhabitants there enjoy a continual Day. On the contrary thoſe that lye within the *Antarctick* Circle remain in continual Darkneſs, having all Night without any Day. Beſides it is likewiſe manifeſt, that all the Parallels between the Æquator and the *Arctick* Circle, are cut, by the Circle bounding Light and Darkneſs, into unequal Portions; the largeſt Portions of theſe Circles remaining in the Light, and the ſmalleſt in Darkneſs: But thoſe Parallels which are towards the *Antarctick* Circle have their greateſt Portions in Darkneſs, and their leaſt in the Light; and the difference of theſe Portions will be greater or leſs, according as the Circles are nearer to the *Pole* or to the Æquator. Therefore in this Poſition of the *Earth*, when the *Sun* is ſeen in ♋, the Inhabitants of the *Northern Hemiſphere* will have their Days at the Longeſt, and their Nights the Shorteſt; and the Seaſon of the Year will be Summer. But in the *Southern Hemiſphere* the Inhabitants will have their Nights longeſt, and their Days ſhorteſt; and they will be in their Winter Seaſon.

The Arctick and Antarctick *Circles,*

AND in every Place the length of the longeſt Days will be the greateſt, and the Nights the ſhorteſt, according as the Place is further removed from the Æquator, and comes nearer the *North Pole*. We ſee likewiſe that, of all the Parallels, there is only the Æquator which is cut into equal Parts by the Circle bounding Light and Darkneſs, they being both of them great Circles: And therefore it is only the Inhabitants of the *Earth* that live in the Æquator, that have their Days conſtantly equal to their Nights, throughout the whole Year.

When the Days are Longeſt. When Shorteſt.

Lecture VII.

WHILE the *Earth* goes on from ♑ by ♒, ♓ to ♈, in which time the *Sun* is ſeen to paſs thro' the Signs ♋, ♌ and ♍, he will appear to return by little and little towards the Æquator; and when the *Earth* is arrived at ♈, the *Sun* will appear in ♎, where the common Section of the Æquator and the Ecliptick always keeping Parallel to its ſelf, will paſs thro' the Center of the *Sun*, and then the *Sun* will appear in the Celeſtial Æquinoctial: At which time the Days will again be equal to the Nights, to all the Inhabitants of the *Earth*; juſt after the ſame way as it was when the *Earth* was in ♎, in that Poſition the Circle bounding Light and Darkneſs paſſing thro' the *Poles*.

The Appearances when the Earth *is in* Aries.

THE *Earth* moving on thro' ♈, ♉ and ♊, the *Sun* will be ſeen to go in the Ecliptick thro' ♎, ♏ and ♐, and will appear to decline from the Æquator towards the *South*; ſo that when the *Earth* is really in ♋, the *Sun* will appear among the *Stars* near the Conſtellation ♑. And whereas the *Axis* B A does not change its Inclination, but does always retain its Parallelíſm, the *Earth* will have the ſame Aſpect and Poſition in reſpect to the *Sun*, that it had when it was in ♑; but with this difference, that when the Tract within the *Polar* Circle K L was in continual Light while the *Earth* was in ♑; now the *Earth* arriving at ♋, that ſame Tract will be altogether in Darkneſs, and the Beams of the *Sun* can not reach it. But the oppoſite Space within the Circle F G, will be in a continual illumination, and at the *Pole* A there will be no Night for the ſpace of ſix Months.

The Appearances when the Earth *is in* Cancer.

HERE likewiſe of the Parallels between the Æquator and the *North Pole*, the illuminated Portions are much leſs than the Portions which remain in Darkneſs; the contrary of which happened in the former Poſition, ſo likewiſe the *Sun* at mid-day will appear vertical, or directly over Head to all the Inhabitants that live in the Tropick M N, ſo that it will appear to have deſcended towards the *South* from the Parallel T C to the Parallel M N, thro' the Arch C Q N, which is 47 Degrees. Therefore the Inhabitants of all Places of the *Earth* that are beyond the Tropicks, towards either of the *Poles*, have the *Sun* in their Summer 47 whole Degrees nearer to their Vertex or to the Point directly over their Heads, than in the oppoſite time of Winter. This change of Situation in reſpect to the *Sun*, does not ariſe becauſe the *Earth* is raiſed or depreſſed, but on the contrary, becauſe it is no where depreſſed and no where raiſed: But with its *Axis* keeps the ſame immutable Poſition, in reſpect of the Univerſe, only going round the *Sun* which is placed in the Center of its orbit, and the *Axis* thereof retaining the ſame Inclination to the Plane of the Orbit, and the ſame Situation in reſpect to any other fixed Line.

How all theſe Appearances may be repreſented to the Eye.

ALL we have here ſaid will appear evident to our Eyes, if we light a Candle in a dark Room, and take a ſmall Globe of two or three Inches Diameter, in which we muſt mark the *Poles*, the Æquator, ſome Parallels, and ſome Meridians, or Circles paſſing from *Pole* to *Pole*: Then we muſt ſo hold this Globe before the Candle, that its *Axis* may not be Perpendicular to the Plane of the Table on which the Candle ſtands, but let it be inclined to it, in an Angle nearly of 66½ Degrees; then place the Globe in ſuch a manner, that one of its *Poles* may point directly *Northward*, and let the light of the Candle firſt reach from *Pole* to *Pole*, that is, let the Circle bounding Light and Shadow firſt paſs thro' the two *Poles* of the Globe: Then let the Poſition of the *Axis* be well obſerved, and then move the Globe round the Candle with your Hand, in a Circle Parallel to the *Horizon*, holding it ſo that the *Axis* may always point the ſame way, and retain the ſame Inclination to the *Horizon.* This done you will ſee that the Flame of the Candle will in the ſame manner illuminate this Globe, as the *Sun* actually does the *Earth*: And the *Poles* of the Globe, its Æquator and Parallels, will undergo the ſame viciſſitudes of Light and Darkneſs, which we have now explained.

The like Appearances from any other Planet *that turns round its* Axis.

THE like *Phænomena* or Appearances may be obſerved from any other *Planet* that turns round its *Axis*. For Example: *Jupiter* performs his Gyration in the ſpace of ten Hours; and therefore a *Jovian* or an Inhabitant of *Jupiter*, will ſee the whole Heavens, and even our *Earth* together with the *Sun*, to have a rapid Motion round his Body in the ſpace of ten Hours: But the *Axis* of *Jupiter* is very nearly Perpendicular to the Plane of his Orbit, and therefore the Circle bounding Light and Darkneſs in *Jupiter*, does always nearly paſs thro' his *Poles*; and therefore the Days and Nights in that *Planet* are almoſt conſtantly equal; hence it ſeems the *Jovians* enjoy an Uniform temperate Seaſon, without being uneaſy at the approaching Heats of the Summer or the Colds of the Winter.

The Axis *of the Ecliptick.*

IF thro' the Center of the *Sun* or *Earth* (it is no matter which, for theſe two Points at the Diſtance of the *Stars* will be ſeen to coincide) there be raiſed a Line which is Perpendicular to the Plane of the Ecliptick, and this Line be produced to the Heavens, it is called the *Axis* of the Ecliptick; and the two Points which this Line on both ſides produced does tend to in the Heavens, are called the *Poles* of the Heavens. Now if we imagine great Circles to paſs thro' theſe *Poles* and by every *Star* or *Planet*, they will all be Perpendicular to the Plane of the Ecliptick. Theſe Circles are called *Secondaries* of the *Ecliptick*, or *Circles of Latitude*. And an Arch of one of theſe

The Secondaries of the Ecliptick.

The Latitude of a Star. *The Longitude of a* Star.

theſe Circles intercepted between any *Star* and the Ecliptick is called the *Latitude* of that *Star*, or its Diſtance from the Ecliptick; which may be either *North* or *South*, according as the *Star* is upon the *North* or *South* ſide of the Ecliptick. So alſo an Arch of the Ecliptick between the firſt Point of ♈, or its interſection there with the Æquator, and the Point where the Circle of Latitude paſſing thro' a *Star* cuts the Ecliptick, is called the *Longitude* of that *Star*.

The Meridians. *The Latitude of a Place.* *Its Longitude.*

AFTER the ſame manner if there be conceived innumerable Circles to paſs thro' the two *Poles* of the *Earth*, and thro' each place on its Surface, they will all be Perpendicular to the Æquator, and they are called Secondaries of the Æquator: But in reſpect of the Places thro' which they paſs, they are called *Meridians*, becauſe when the *Sun* is ſeen in any place in the Plane of ſuch Circle, it will be mid-day to the Inhabitants of that Place. The Arch of one of theſe Secondaries intercepted between any place and the Æquator, is called the *Latitude* of the Place; or its Diſtance from the Æquator, which may be likewiſe either *North* or *South*; And that Arch of the Æquator, that lies between the Interſection of the Secondary paſſing through any Place, with the Æquator, and any other fixed Point in the Æquator, is called the *Longitude* of that Place.

Plate III *front. p. 74.*

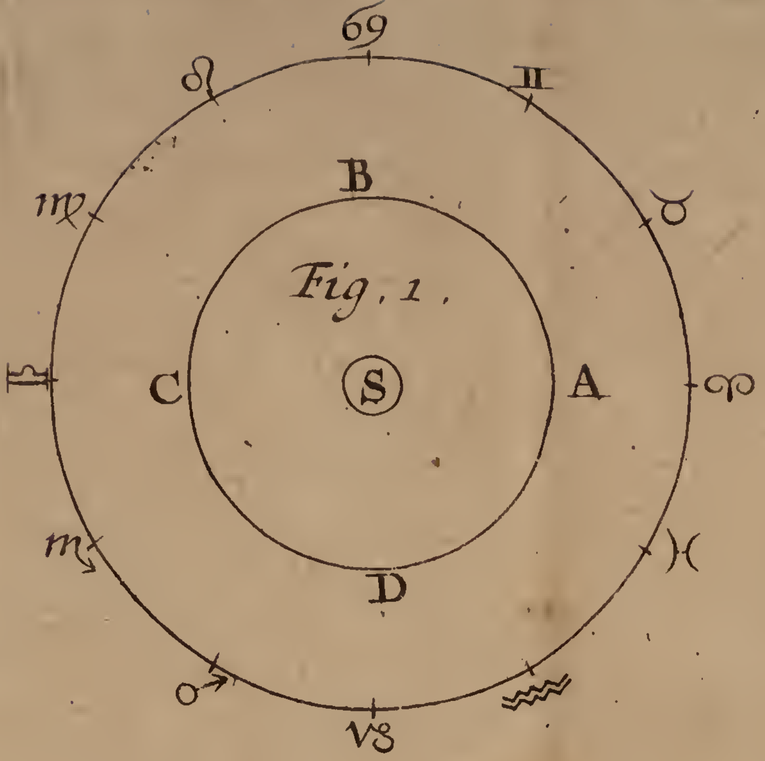


Fig. 1.

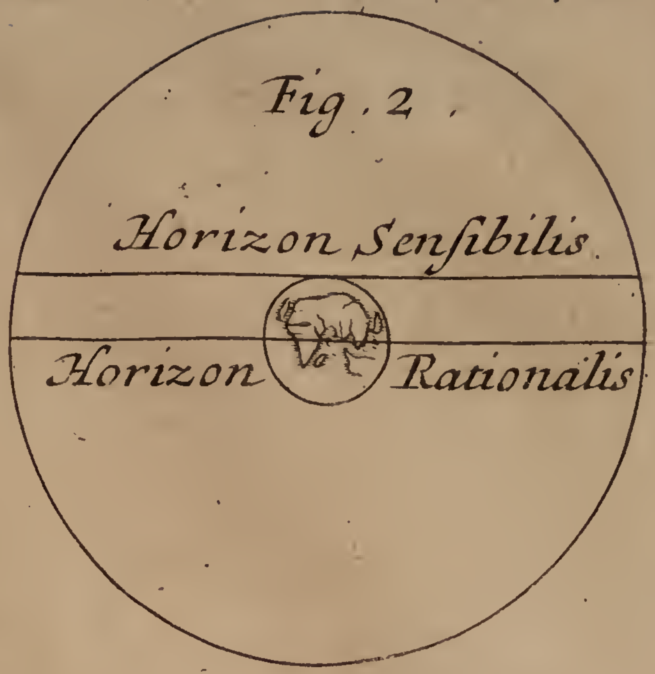


Fig. 2.

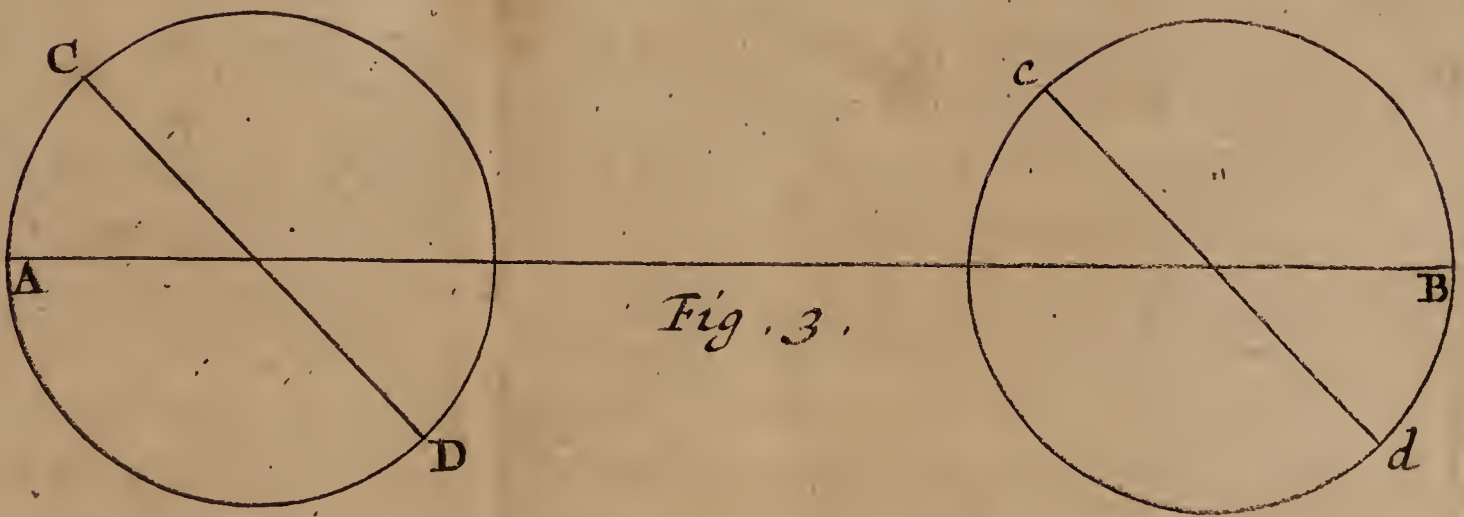


Fig. 3.

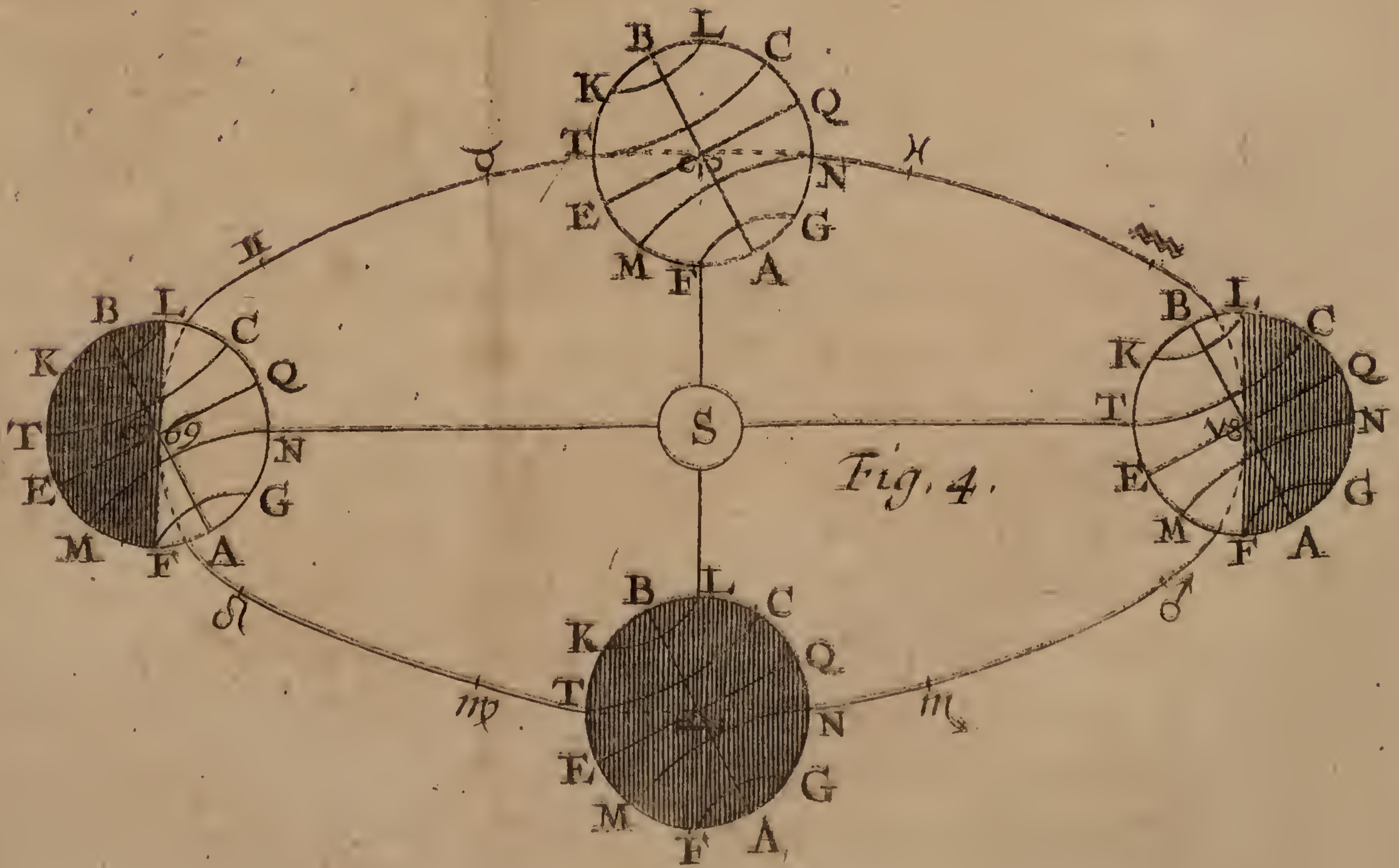


Fig. 4.

LECTURE VIII.

Concerning ſeveral other Phænomena *or Appearences, which depend on the Motion of the* Earth.

SINCE the *Earth* turns ſo round the *Sun* that its *Axis* always remains Parallel to it ſelf, it ſeems neceſſary that this *Axis*, at different Seaſons of the Year, ſhould point to different *fixed Stars*, and that the *Star* or Point of the Heavens, which is directly over the *Pole* of the *Earth* in the Summer, ſhould not be ſo directly over it in the Winter; but that the *Axis* ſhould point to another *Star*, whoſe diſtance from the former ſhould be equal to the whole Diameter of the *Earth*'s Orbit.

The Axis *of the* Earth *ought to point to different* Stars *at different times of the Year.*

FOR let ACBD be the Orbit of the *Earth*, in whoſe Center is the *Sun* S; A B the Diameter of the Orbit: When the *Earth* is at A, its *Axis* is directed to a *Star* E, which is directly over the *Pole* of the *Earth*: Now when the *Earth* comes to the oppoſite Point of the Orbit B, the *Axis* being in a Poſition Parallel to its former Poſition, it will no longer point to the *Star* E, but to another *Star* F, which two *Stars* will be diſtant from each other, the whole length of the Diameter of the great Orbit. But the Angular or obſervable diſtance of the *Stars* is the Angle E B F, which is equal to the Angle A E B, by the 29th Prop. 1ſt. Book of *Euclide*. But the Angle A E B is the Angle under which the Diameter of the great Orbit or Orbit of the *Earth* is ſeen from the *Star* E, which Angle E B F or A E B is called the *Parallax of*

Plate IV. Fig. 1.

The Parallax of the great Orbit.

the great Orbit, and if it could be obſerved, we might by it find the diſtance of the *Star* E from the *Earth*, in reſpect of the *Sun*'s diſtance from us. For in the Triangle E A B, we have the Angle E which is equal to the Angle E B F, which we ſuppoſe we can obſerve; we have likewiſe the Angle E A B, which in the *Equinoctial points* is always a Right Angle; and in the *Solſtices* it is equal to the Inclination of the *Earth*'s *Axis* to the Plane of the Ecliptick, and is always equal to the Viſible diſtance of the *Sun* from the *Pole*: Hence in this Triangle we have all the Angles; we have likewiſe the ſide A B, and conſequently by *Trigonometry* we can find the ſide A E, or EB, the diſtance of the *Star* E from the *Earth*.

This Parallax ſcarcely to be obſerved.

BUT the Truth is, that the diſtance of the *Stars* is ſo great in reſpect of A B, and the Angle E B F is ſo very ſmall, that there can be no Inſtruments made nice enough to obſerve it exactly; and they who have taken moſt Pains to find it out, could never obſerve it to be ſo great as one Minute: And ſince in the Obſervations of ſuch ſmall Angles, Errors are ſcarcely to be avoided, and ſuch too as will in the Computation produce prodigious differences in the diſtances which depend upon them; we cannot ſafely truſt ſuch Obſervations: For if with Mr. *Flamſteed* we ſhould ſuppoſe the Parallax, or the Angle E B F, to be 42 Seconds, and there be an Error committed in Obſervation, which makes the Angle 25 Seconds greater than it really is, (and no Man can be ſure that he has not committed ſuch an Error) the diſtance of the *fixed Stars* in that caſe will really be double of what our Obſervation makes it. But if the Obſervations happen to be leſs accurate, ſo that there may be a Minute or more between them and the Truth, (and moſt of our Obſervations are ſuch) the diſtance that ariſe from the Computations made on ſuch Obſervations, will be prodigiouſly wide of one another, and all of them very different from the Truth.

The Diſtance of the Stars uncertain.

HITHERTO we have ſuppoſed the *Axis* of the *Earth* to have remained in an immutable Poſition, and to have continued in an exact Paralleliſm, and that the *Earth* had only two Motions, one Annual round the *Sun*, the other Diurnal round its *Axis*. But the *Aſtronomers*, from the Obſervations of many Years, have found that the *Axis* of the *Earth* has not exactly kept its Paralleliſm, but has deviated a little from that Poſition, ſo that tho' the Variation in the ſpace of two or three Years be ſcarcely ſenſible, yet in many Years, or in a Century or two, it is very obſervable: And therefore while we were explaining the Appearences of one Year, we ſpoke nothing of this *Aberration*, for that could no ways diſturb the *Phænomena* that were then to be explained; yet in the compaſs of ſeveral Years, this mutation or change of the Poſition of the *Earth*'s *Axis* becomes very remarkable. So the Direction of the *Axis* has been ſenſibly changed, tho' its Inclination to the Plane of the Ecliptick has remained the ſame, and from hence we find, that the *Axis* of the *Earth* has another Motion which is here to be explained.

The Axis *of the* Earth *does not preſerve an exact Paralleliſm.*

Let the Line D C H repreſent a Portion of the *Earth*'s Orbit, and let the Center of the *Earth* be C; from which erect C E perpendicular to the Plane of the Ecliptick, meeting with the Concave ſurface of the Heavens in E: This Line C E will be the *Axis* of the Ecliptick, and E the *Pole* of it. Let C P be the *Axis* of the *Earth* produced to the Heavens, P will be the *Pole* round which the Heavens have an apparent diurnal Revolution. Thro' the two Points E and P draw a great Circle E P A, which paſſing thro' the *Poles* of both the Ecliptick and Æquator will be Perpendicular to both thoſe Circles. Let it meet with the Ecliptick in A; the Arch P A will meaſure the Angle P C H, which is the Inclination of the *Axis* of the *Earth* to the Plane of the Ecliptick, that is, it will be 66½ Degrees; and therefore the Arch E P which is its complement to a Quadrant,

Plate IV. Fig. 2.

The Axis *of the* E*cliptick.*

The Pole of the World moves backward in a leſſer Circle Parallel to the Ecliptick.

Quadrant, will be 23½ Degrees; which Arch will meaſure the Angle E C P, that the *Axis* of the Ecliptick and the Æquator make with one another. From the *Pole* E deſcribe thro' P a leſſer Circle P F G, which will be Parallel to the Ecliptick; and ſince the *Axis* of the *Earth* always keeps the ſame invariable Angle with the *Axis* of the Ecliptick, it will always be directed to ſome Point in the Periphery P F G, and the *Pole* of the World muſt always be ſomewhere placed in it: So likewiſe if the *Axis* of the *Earth* retained the ſame direction without any change, as often as the *Earth* came to the Point of its Orbit C, the Pole of the Heavens would be conſtantly in the indiviſible Point P: But we find that the *Pole* of the World does conſtantly change its place in the Periphery P F G, and the *Axis* of the *Earth* which before pointed to P, after 72 Years will look to another Point Q, which is one Degree from P towards the *Weſt*. And by this means the *Axis* of the *Earth*, or of the World, is carried in a *Conical Motion*, or deſcribes the Surface of a *Cone*, whoſe Vertex is in the Center of the *Earth*, and its *Baſe* is the Circle P F G; and the *Pole* P will conſtantly move in the Periphery P F G, with a very ſlow and retrograd Motion, from the *Eaſt* to the *Weſt*, and does not finiſh its Circulation in leſs than 25920 Years, after which time the *Pole* having left the *Star* at P, does again return thither. Hence it follows, that the *Star* which is now the *Polar*, and directly over the *Pole* of the *Earth*, after 12960 Years, which is half the Period of the *Polar* Revolution, will be 47 Degrees diſtant from the Pole, which will then be directed to G.

The Solſtitial Colure.

The Circle E P A being Perpendicular to both the Ecliptick and the Æquator, will be the *Solſtitial Colure*, and A will be the *Solſtitial Point*, which Point of the Ecliptick is moſt diſtant from the Æquator: Now after the *Axis* of the *Earth* produced comes into the Poſition C Q, if there be drawn thro' the Poles of the Ecliptick

cliptick and the Æquator the Circle E Q B, this Circle will then be Perpendicular to both Æquator and Ecliptick, and therefore when the *Axis* of the *Earth* is in the Poſition C Q, the Circle E Q B will be the *Solſtitial Colure*, and the *Solſtitial* Point will be B, where that Circle interſects the Ecliptick; and therefore the *Solſtitial* Points will move backwards equally with the *Poles*; the Motion of the *Pole* being in the Circle P Q G which is Parallel to the Ecliptick, the Arches P Q and A B will be like or ſimilar; ſo that when P Q is an Arch of one Degree, A B will likewiſe be an Arch of one Degree.

The Solſtitial *Points move backward.*

HENCE the *Solſtitial* Points will always be receding from the *Stars* backwards, ſo that if the *Solſtitial* Point be this Day near the *Star* A, after 72 Years it will be in B, one Degree removed towards the *Weſt* of the *Star* A. And ſince the *Solſtitial* Points move conſtantly backwards, the Æquinoctial Points which are always 90 Degrees diſtant from the *Solſtices*, will alſo move conſtantly backwards; and ſo likewiſe muſt all the other Points of the Ecliptick neceſſarily move back, equally with the *Solſtices*, becauſe they keep conſtantly the ſame diſtances from them: Thus ſince between the *Solſtice* and the interſection of the Æquator and the Ecliptick, there are 90 Degrees, or a Quadrant of a Circle, when the *Solſtice* has moved one Degree *Weſtward*, the Æquinoctial interſection muſt likewiſe move one Degree *Weſtward*, otherwiſe they could not always keep the ſame diſtance from one another: Therefore the Æquinoctial Points, and all the other Points of the Ecliptick, do move continually backwards, or towards the *Weſt*. And this Motion is ſaid to be *in Antecedentia*, to the *Weſtward*, and contrary to the order of the Signs: As the other Motion whereby the *Earth* and all the Planets are carried round the *Sun* to the *Eaſtwards*, is ſaid to be *in Conſequentia*, in Conſequence, or according to the Order of the Signs, that

The Æquinoctial Points move likewiſe backwards.

The Motions in Antecedentia.

The Motions in Conſequentia.

that is from ♈ to ♉ ♊, *&c.* And this backward Motion of the Æquinoctial Points, is called the *Preceſſion* of the Æquinoxes, by which they are carried conſtantly back unto the preceding Signs or *Stars*, and fall more and more behind the ſucceeding *Stars.*

The Motion of the Æquinoctial Points backwards makes the Stars *ſeem to move forwards, or to the* Eaſt.

SINCE the *fixed Stars* remain immoveable, and the common Interſection of the Æquator and the Eckliptick conſtantly falls backward, it muſt neceſſarily happen that the Diſtance of the *Stars* from the Æquinoctial Points be conſtantly changed, and the Interſections moving *Weſtward*, the *Stars* will ſeem to remove more and more *Eaſtward* in reſpect of the Æquinoctial Points: And therefore the Longitudes of the *Stars* which are computed from the firſt of Point ♈, or the Vernal interſection of the Æquator and Ecliptick, muſt conſtantly increaſe; and all the *Stars* will ſeem to have a Motion *Eaſtward*, not that they have really any ſuch Motion, but becauſe the Æquinoctial Point has a contrary Motion to the *Weſt*, ſo that the Diſtances of the *Stars* or their Longitude from the firſt Point of ♈ reckoned *Eaſtwards*, becomes conſtantly greater.

The Conſtellations have changed their places.

HENCE it is, that all the Conſtellations have changed their places, and have deſerted the Stations they kept when they were obſerved by the firſt *Aſtronomers.* Thus the Conſtellation of the *Ram*, which in *Hipparchus*'s time was near the Vernal interſection of the Æquator and Ecliptick, and gave its Name to that Portion of the Ecliptick, is now removed from that Interſection a whole Sign, or a twelfth Part towards the *Eaſt*, and is got into the Sign or Portion of the Ecliptick called ♉ or the *Bull*: Thus alſo the Conſtellation ♉ or the *Bull* does now reſide in *Gemini* or the *Twins*, and the *Stars* which are called *Twins* are at this Day advanced to ♋ or the *Crab*; the *Stars* in the *Crab* are got into the place which was formerly poſſeſſed by the *Lyon*, and the *Lyon* has driven the *Virgin* a whole Sign forward; and ſo every

Conſtellation has ſince the firſt Obſervation changed place with the following. But here it is to be obſerved, that tho' the Conſtellations or Images have left their places, yet the twelve Portions of the Ecliptick, which are called *Dodecatimoria*, retain ſtill the ſame Names which they had at firſt in the time of *Hipparchus*: But to diſtinguiſh them from the Conſtellations, the Portions of the Ecliptick are called *Anaſtrous* Signs, or Signs without *Stars*; and the Conſtellations are called the *Starry* Signs.

SOME Antient *Aſtronomers* ſuppoſed the Interſections of the Æquator and Ecliptick to be immoveable, and becauſe they found that the *Stars* changed their diſtances from theſe Interſections, they therefore imagined the Orb or Sphere in which the *fixed Stars* were placed, to have a ſlow Revolution about the *Poles* of the Ecliptick; ſo that all the *Stars* performed their Circulations in the Ecliptick or its Parallels, in the Space of 25920 Years; after which time the *Stars* would again return to their former places. This Period of time, which is five times greater than the Age of the World, they called the great Year; and imagined that when it was finiſhed, every thing would begin again, and all things happen and come up in the ſame order they do now.

The great Year.

THE Phyſical and efficient cauſe of the Preceſſion of the Equinoxies, was unknown to all the *Aſtronomers* before *Sir* ISAAC NEWTON; none of them being able to gueſs from whence it did proceed. But *Sir* ISAAC NEWTON having conſidered the Laws of Motion and Gravity, hath clearly demonſtrated that it doth ariſe from the broad Spheriodical Figure of the *Earth*: And that this broad Spheriodical Figure ariſes from the Rotation of the *Earth* round its *Axis*.

ALTHO' the *Earth* in its Annual Motion does ſo go round the *Sun* that it always performs its Period in equal intervals of time; yet its Motion in its Orbit is obſerved not to be equa-

The Motion of the Earth *in its Orbit not equable.*

ble and uniform, but in ſome places it moves quicker, in other places it ſlackens its pace; and therefore the Apparent Motion of the *Sun* in the Ecliptick cannot be regular and Uniform: And he is not obſerved to go thro' the ſame ſpace of the Ecliptick every Day. In our Summer he is obſerved to go with a ſlower Motion, in our Winter he moves ſomewhat faſter; and the difference of theſe Motions in Summer and Winter is ſuch, that his place in the Ecliptick is ſometimes two Degrees above what it would be, if he had conſtantly kept the ſame pace; and ſometimes it is two Degrees leſs: On which account the *Sun* is obſerved to ſpend near eight Days more time in the *Northern* Signs of the Ecliptick, than in the *Southern* Signs; ſo that from the time of the *Sun*'s being in the *Vernal* Æquinoctie, 'till his coming into the *Autumnal*, there are 186½ Days; in which time by his Apparent Motion he is ſeen to deſcribe one half of the Ecliptick. But from the *Autumnal* Æquinoctie to the Vernal, there are only 178½ Days, in which ſpace of time he finiſhes his courſe thro' the other half of the Ecliptick, and viſits all the *Southern* Conſtellations. We are alſo aſſured by the Obſervations of *Aſtronomers*, that the Apparent Diameter of the *Sun* in Winter, when the Motion of the *Sun* is quickeſt, is greater than the Apparent Diameter in the Summer, when he ſlackens his pace; and the Difference is ſo great, that when the *Sun* appears biggeſt, he is ſeen under an Angle of 32 Minutes 47 Seconds; but when he appears leaſt, he ſubtends an Angle only of 31 Minutes and 40 Seconds, and therefore the *Sun* muſt be farther from us in Summer than in Winter.

Our Summer is eight Days longer than Winter.

The Apparent Diameter of the Sun greater in Winter than Summer

Some *Aſtronomers* too pertinaciouſly keeping to Circular Orbits, that they might give a Satisfactory account of theſe Appearances, ſuppoſed that the *Earth* did really move with an equable Motion in the Periphery of a Circle, and that if it were ſeen from the Center of that Circle, Lecture VIII.

Plate IV. Fig. 3. *The Motion of the* Earth *in an Excentrick Circle.*

Circle, it would be obſerved to deſcribe equal Angles round it; but they ſuppoſed the *Sun* to be removed from that Center at ſome diſtance. Let the Circle A B C D be the Orbit of the *Earth*, whoſe Center is E, and imagine the Center of the *Sun* not to be in E, but in S. Now when the *Earth* is in A, the *Sun* will be obſerved in the Point ♈, and when the *Earth* comes to B, the *Sun* will be obſerved in ♋: And again the *Earth* being arrived at C, the *Sun* will appear in ♎; ſo that while the *Earth* deſcribes the Arch A B C, which is more than a Semicircle, the *Sun* will appear to have gone thro' but one half of the Ecliptick; and the *Sun* will ſeem to have performed his Journey thro' the other half, while the *Earth* is deſcribing the other Portion of her Orbit A D C. Now ſince the Arch A B C is greater than the Arch A D C, it is eaſy to ſee that the *Sun* muſt take more time to deſcribe, by its apparent Motion, that half of the Ecliptick ♈, ♋, ♎, than the other ♎, ♑, ♈. Moreover when the *Earth* is in B, it is further diſtant from the *Sun* than when it is in D: And if its Motion were in itſelf perfectly equable, yet when it is ſeen from the *Sun*, which is not the Center of equable Motion, it would from thence appear to be unequal: In B it would appear to be ſloweſt of all, and in D to be the quickeſt of all. But the Apparent Motion of the *Sun* in the Ecliptick is conſtantly equal to the Motion of the *Earth* ſeen from the *Sun*; and therefore by this Suppoſition we can give an eaſy account why in our Summer the *Sun* appears to have a ſlow Motion, and in the Winter a quicker; ſo that the unequal Motion of the *Sun* or *Earth* is not ſo in reality, but only Opticall and Apparent; ariſing only from this, that the *Sun* is not exactly in the Center of the *Earth*'s Orbit in E, but at ſome diſtance from it at S: So they affirmed that a Spectator in E would always Obſerve that the *Earth* had a moſt exact uniform Motion round that Center in its Orbit.

THIS *Hypotheſis* appears at firſt ſight to be ſimple enough, and to anſwer well the Appearances we have related; and all the *Aſtronomers* before *Kepler* embraced it as a true *Hypotheſis*. For they held it for an undoubted truth, that all the Motions of the Heavens were axactly Circular, and in themſelves equable: But after the Great *Kepler* had more accurately ſurveyed theſe Motions, and relying upon the Obſervations of the moſt Induſtrious *Tycho Brahe*, he then found that the Circular *Hypotheſis* would by no means anſwer to the true Motions of the *Planets*: And by a moſt certain and infallible Method of reaſoning, he has ſhown that the Motions of the *Planets* are neither equable in themſelves, nor are their Orbits exact Circles. For by the Obſervations of *Tycho*, he has proved beyond all diſpute, that the Figure of a Planetary Orbit is an *Ellipſe*, which is deficient from a Circle, or of the form of an Oval; and that the *Planets* Motion in this Ellipſe is really unequal, ſometimes quicker, and ſometimes ſlower; and that according to its diſtance from the *Sun* the *Planet* ſlackens or quickens its Motion.

The true Motions of the Planets *are neither in Circles nor equable.*

The Elliptick Orbits of the Planets.

NOW the *Ellipſis* is a curved Line Figure, which the *Geometers* commonly ſhew by cutting a Cone or a Cylinder obliquely: But its nature will be more clearly apprehended by beginners, from the following Deſcription. Imagine two ſmall round Sticks to be faſtned in any Plane or Paper, one in the Point H, the other in the Point G; and ſuppoſe a Thread doubled with the two ends tyed together, whoſe length muſt be greater than the diſtance of the Points G and H, which Thread put over the two round Sticks: And let there be a Pen put in the doubling of the Thread, which may keep it always ſtretched with the ſame force. This Pen going in this manner round will deſcribe by it its Motion a curve Line, which is the *Ellipſe* we now ſpeak of. And if without changing the length of the Thread, we ſhould bring the round Sticks a little cloſer together, we ſhall then have another Ellipſe of a different kind from the former, and which will come nearer to a Circle: And by bringing them ſtill nearer, we ſhall always change the Form of our Ellipſe, and bring it nearer to a Circle, 'till the Sticks come to be joined together in one; and then the Pen in the doubling of the Thread will deſcribe an exact Circle. Either of the Points G or H is called the *Focus* or Navil of the Ellipſis, and if we biſect H G in C, the Point C is called its Center; the Line D K paſſing thro' each *Focus*, and at each end meeting with the Ellipſe, is called its *Axis*: Hence it is evident, that if from any Point of the Ellipſis, there be drawn to the two *Focus*'s, as for Example from B, two Lines B H and B G, theſe two Lines joined together will always be equal to the *Axis* of the Ellipſis, and likewiſe equal to the length of the Thread, bating the Diſtance of the two *Focus*'s.

The Focus *or* Umbilicus.

The Axis.

NOW tho' this be the Form of the Orbit which the *Planets* deſcribe, yet the Place of the *Sun* is not the Center of it, but he takes his Reſidence in one of the *Focus*'s: And the *Axis* of the Ellipſe A P, is called the Line of the *Apſides*; the Point A is termed the *higher Apſis*, and the *Aphelion*; the Point P is called the *lower Apſis*, and the *Perihelion*: And S C the Diſtance between the *Sun* in the *Focus* and the Center, is called the *Excentricity*. If from the Center C, there be erected upon the *Axis* the Perpendicular C E, meeting with the Orbit in E, and there be drawn from the *Focus* the Line S E; this Line is called the *Mean Diſtance* of the *Planet* from the *Sun*, which is equal to half the *Axis*; it exceeding the ſhorteſt Diſtance by as much as the longeſt Diſtance exceeds it.

Plate IV. Fig. 5.

The higher Apſis *or* Aphelion.

The lower Apſis *or* Perihelion.

The Excentricity.

The Mean Diſtance.

Lecture VIII.

IN the Planetary Orbits, the Forms of the Ellipſes do not differ much from Circles; and in the Orbit of the *Earth*, the Excentricity SC is only 17 of ſuch parts as SF the Mean Diſtance conſiſts of a 1000, which Excentricity is but half of that which the *Aſtronomers* that ſuppoſed Circular Orbits, attributed to the Diſtance of the *Sun* from the Center.

The Rule by which the Planets Motions are regulated, is the equable deſcription of Elliptick Areas.

THE Motion of a *Planet* in the Periphery of an Ellipſe, is not at all equable; yet it is regulated by a certain immutable Law, from which it never deviates; which is, that a Line or Ray drawn from the Center of the *Sun* to the Center of the *Planet*, which is carried about with an Angular Motion, does ſo move, that it deſcribes or ſweeps an Elliptick *Area*, always proportional to the Time. Thus, let the *Planet* be in A, from whence in a certain Time let it go to B; the Space or Area the Ray SA deſcribes is the Triline ASB: When afterwards the *Planet* comes to P, and from the Center of the *Sun* S, there be drawn the Line SD, ſo that the Elliptick Space or Area PSD, may be equal to the Area ASB; then in that Caſe, the *Planet* will move thro' the Arch PD, in the ſame compaſs of time that it did thro' the Arch AB, which Arches muſt be unequal, and nearly in a reciprocal proportion to their Diſtances from the *Sun*; for becauſe of the equal Area's, the Arch PD muſt be ſo much in proportion greater than the Arch AB, as SA is greater than SP. This Law is ſufficiently demonſtrated by the moſt Sagacious *Kepler*, in his Book which he entituled, *Commentaries on the Motion of the Planet* Mars. And unto this his Invention all the *Aſtronomers* do now give their Aſſent; for there is no other Rule to be found, which ſo well ſatisfies all the Appearances of the *Planets* Motions.

The Mean Anomaly.

AN Arch of a Circle, or an Angle, or the Elliptick Area ASG, taken proportional to the Time in which the *Planet* deſcends from A to G, is called the *Mean Anomaly* of the *Planet*. But

The True Anomaly. *The Motion in* Longitude.

the Angle ASG when the *Planet* comes from A to G, is called its *True Anomaly.* But when the Motion of the *Planet* is reckoned from the vernal Interſection of the Æquator and the Ecliptick, or from the beginning of ♈, it is called its *Motion in Longitude*; which is either a Mean Motion, ſuch as the *Planet* would have, did it move uniformly in a Circle round the *Sun*, or elſe the true Motion wherewith the *Planet* deſcribes its Orbit, and is reckoned by the Arch of the Ecliptick it is ſeen to deſcribe; which true Motion is ſometimes accelerated, and ſometimes retarded, according to the Diſtance of the *Planet* from the *Sun*, in the various Points of its Orbit.

The determination of a Planet's *Place in its Orbit.*

BY this means, for any given Time after that the *Planet* has left its *Aphelion*, we find out its Place in its Orbit, *viz*. Let the Area of the Ellipſe be ſo divided by the Line SG, that the whole Elliptick Area may have the ſame proportion to the Area ASG, as the whole Periodical time wherein the *Planet* deſcribes its Orbit, is to the Time given; and then G will be the Place of the *Planet* in its Orbit. The *Geometers* have given ſeveral Methods for dividing in this manner the Area of an Ellipſe, ſome of which we will ſhew in its proper Place.

Why the Sun's *Heat is greater as he is further from us.*

SINCE in our Summer we are further from the *Sun*, and when Winter comes on we begin to approach him; ſome may wonder why the *Earth* grows warmer while it is ſtill further removing from the *Sun*; and again in the Winter why it ſhould be colder notwithſtanding its nearer acceſs to him. But we muſt obſerve that the degrees of Heat and Cold do not altogether depend upon the Diſtances from the *Sun*, but there are other powerful and concurring Cauſes, which have certain effects in this matter: For firſt of all, the direct force of the *Sun*'s Rays is much ſtronger than when they are received obliquely: Now in the Winter the Rays fall upon the *Earth* very obliquely, and their Power is not only diminiſhed on the account of their obliqueneſs, but alſo becauſe the Light is not ſo denſe, there being much fewer rays which can come to a certain Portion of the Surface to Heat it. Moreover the *Sun* being low in the *Horizon* all the Winter, the Beams paſs thro' a much greater quantity of Air, or are deeper immerſed in our Atmoſphere in the Winter, than they are in Summer, when the *Sun* approaches nearer to our Vertex, and the Force of the Rays is broke by the Reflections on ſo many Particles of Air: And the difference is ſo very great, that when the *Sun* is in the *Horizon,* we can look upon him without hurting our Eyes; but when he Riſes higher, there is no enduring his ſight without blinding us.

The Days longer than the Nights, increaſe the Heat.

BUT there is another very powerful Cauſe which produces the variety of Seaſons, which is, that the longer any hard and ſolid Body is expoſed to the Fire, the Hotter it grows. Now in the Summer for ſixteen Hours we are continually in the *Sun*'s heat, and we have only eight Hours in the Night to cool: The contrary of which happens in the Winter, and therefore it can be no Wonder that there ſhould be ſo great a difference of Heat and Cold, in theſe two Seaſons.

SINCE the Power of the *Sun* is greateſt when his Rays fall upon us moſt directly, and when the Days are longeſt; it would ſeem that the greateſt Heat ought to be when the *Sun* enters the Tropick of ♋, for then the *Sun* comes neareſt to our Vertex, and lieth longeſt upon us. But Experience ſhews us, that we have the greateſt Heat after that the *Sun* has left the Tropick; and the Seaſon becomes warmeſt about the end of *July,* in the *Dog-Days,* when the *Sun* has paſſed the Tropick, and is removed from it above a whole Sign.

THAT we may give the true Cauſe of this effect, it is to be obſerved, that the Action of the *Sun* by which all Bodies are heated, is not tranſient, as its Illumination is, but permanent: So that a Body which has been once heated by the *Sun,* retains its Heat for ſometime after the *Sun* has

Plate IV

front. p. 88.

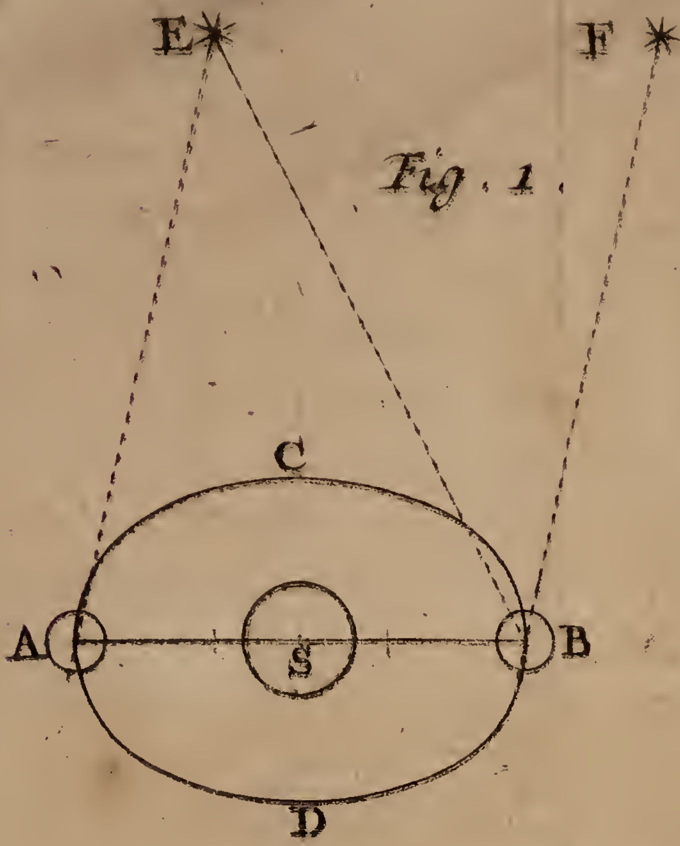


Fig. 1.

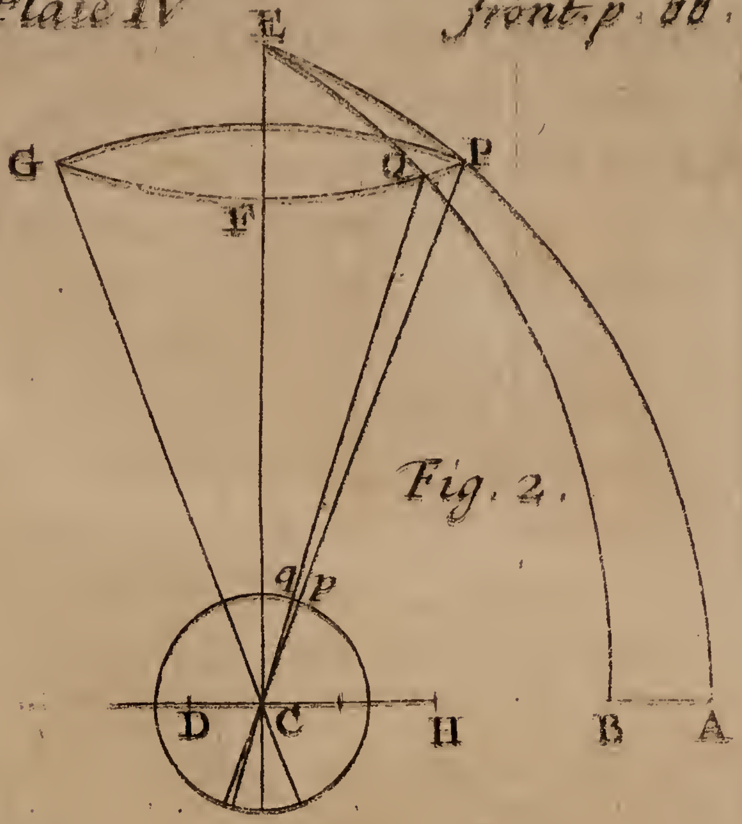


Fig. 2.

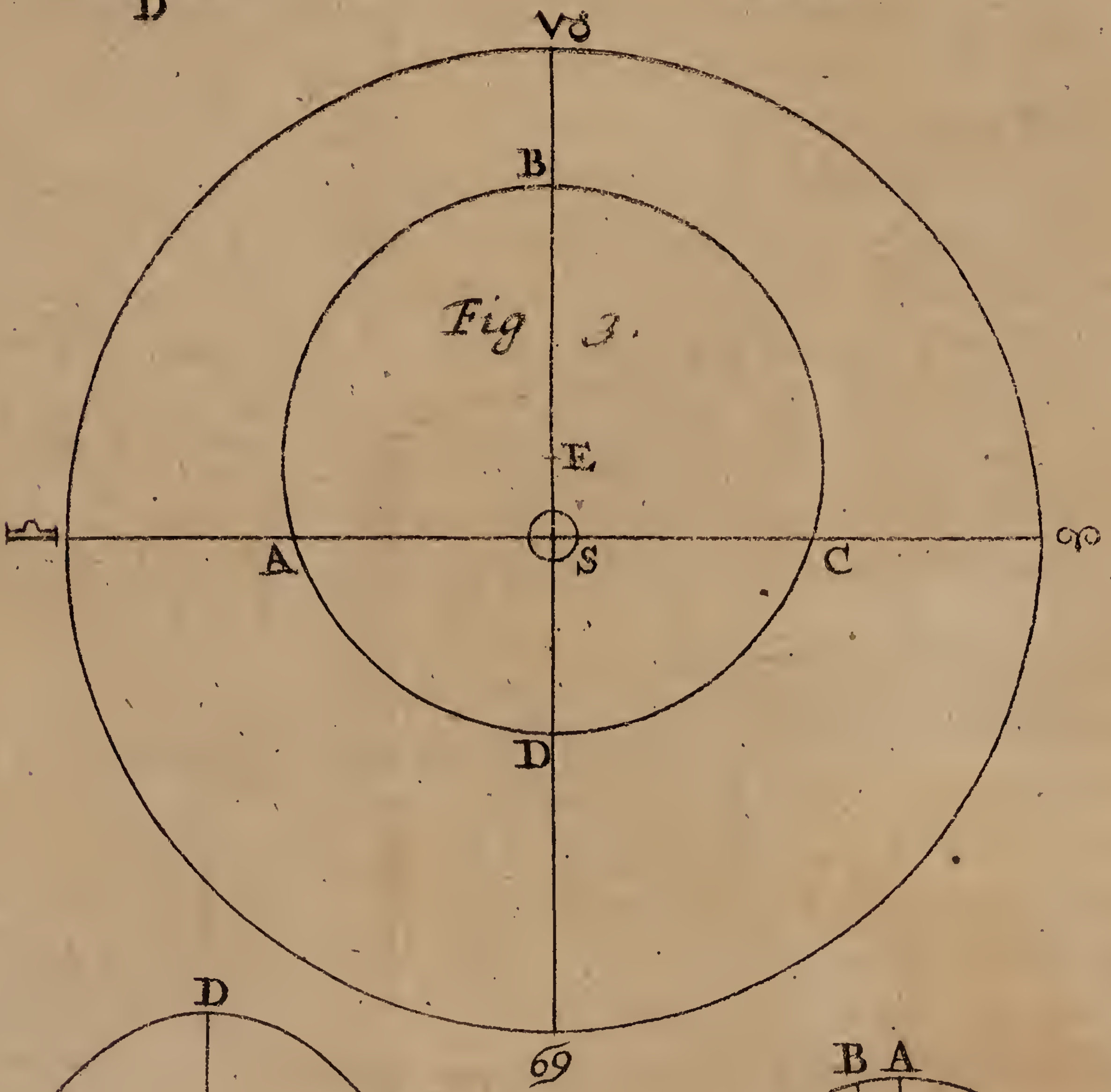


Fig. 3.

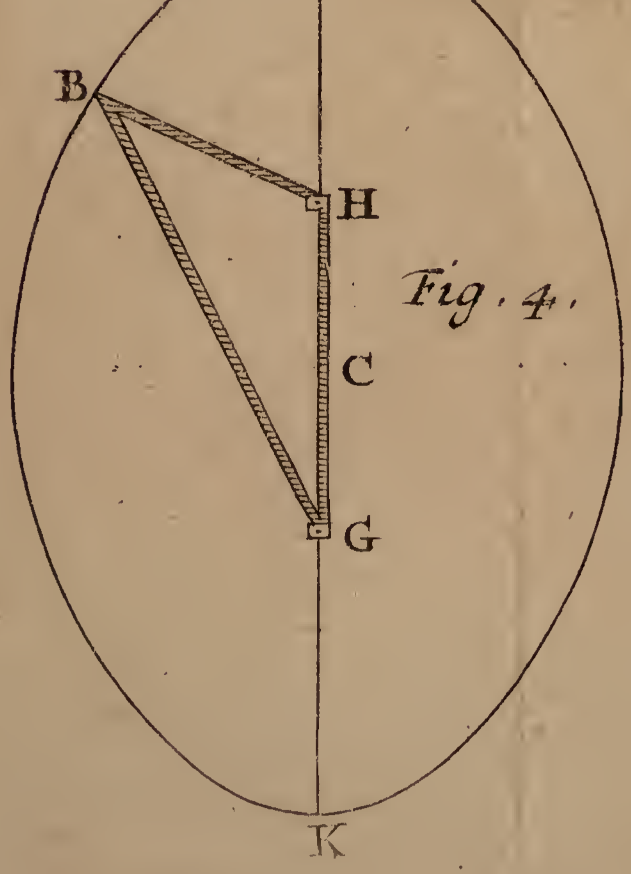


Fig. 4.

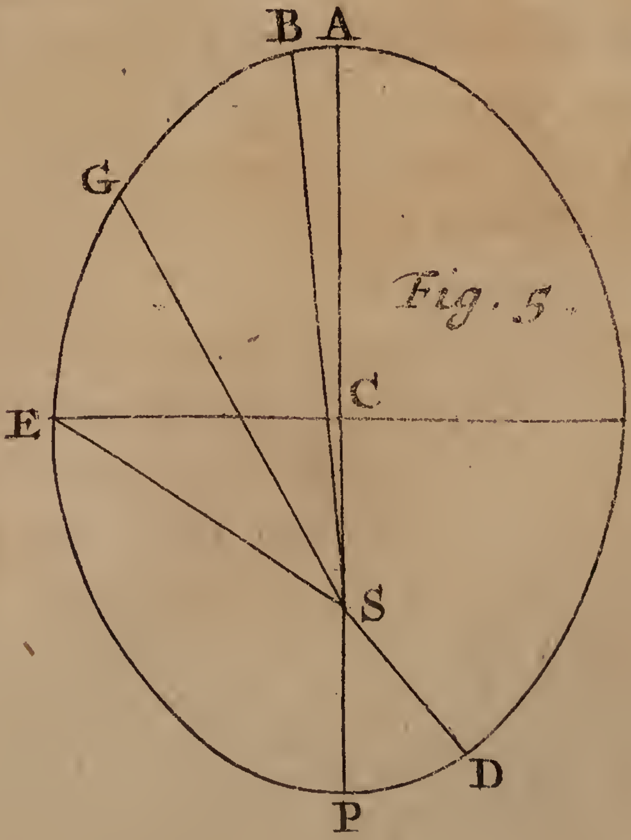


Fig. 5.

gone off it: So that the heating Particles which flow from the *Sun*, and are abſorbed by the heated Body, do for a certain time remain within it, and do therein raiſe a warmth or Heat. But afterwards when theſe Particles fly off, or looſe their Force, the Body begins to cool: And therefore, if the heating Particles which are conſtantly received be more than they which flie away or looſe their Force, the Heat of the Body muſt continually encreaſe. And this is our preſent Caſe: After the *Sun* has entred the *Tropick*, the number of Particles which Heat our Atmoſphere and *Earth*, does conſtantly encreaſe, there entering more in the Day time than what we looſe in the Night time, and therefore our Heat muſt grow greater. Let us ſuppoſe for Examples ſake, that there are a Hundred heating Particles received in the Day time in *Sun* ſhine, and the Night being much ſhorter, there ſhould fly off only fifty of them, other fifty ſtill remaining there to excite Heat: The next Day the *Sun* acting with almoſt the ſame Force, will impart another Hundred Particles, of which no more than one half will fly away in the Night; ſo that on the beginning of the third Day, the number of Particles exciting Heat will be encreaſed by one Hundred: And thus while there are more Particles that excite Heat received in the Day time, than what fly away in the Night, the Heat will conſtantly grow ſtronger. But then as the Days decreaſe, and the Action of the *Sun* becomes weaker, there will at laſt be more Particles that fly away in the Night time, than what we receive in the Day time; by which means the Heat of a Body will grow every Day leſs, and the *Earth* and Air will by degrees Cool.

Why the Heat is not greateſt when the Sun *is in the Summer* Tropick.

LECTURE IX.

Of the Moon, *its* Phaſes *and Motion.*

The Moon *is an Attendant on the* Earth.

OF all the Bodies in the Heavens, if you except the *Sun*, the *Moon* appears to us to be the moſt Splendid and ſhining Globe, and does more particularly belong to our *Earth*, of which ſhe is an inſeparable Companion. And ſhe does conſtantly abide ſo much in our Neighbourhood, that if ſhe were looked at from the *Sun*, ſhe could never be ſeen to depart from us by an Arch greater than ten Minutes: She therefore is tyed to the *Earth*, and waits upon her as an Attendant, going along with the *Earth* round the *Sun* in the ſpace of a Year; but in the mean time ſhe has a proper Orbit of her own which ſhe deſcribes round the *Earth*, in the time of a Month.

It has various ſhapes and Phaſes.

THE Primary *Planets* have the *Sun*, which they regard as a Center, for the Regulator of their Motions; and ſometimes they approach us nearly, at other times they move away to a great Diſtance from us. But the *Moon* like an Earthly Body is kept in our Neighbourhood by a Natural Propenſion or Gravity towards us; by the means of which it is conſtantly turned out of a rectilinear Courſe, and is obliged to perform its Revolution round about us, in the ſpace of 27 Days and ſeven Hours. The *Moon* puts on ſeveral Phaſes or Appearances, and is always changing its Figure; and with the multitude of her Forms ſhe has frequently puzled the Minds and Underſtandings of thoſe *Philoſophers*, who have moſt Contemplated her: Sometimes ſhe encreaſes and grows bigger, then ſhe again wanes, and diminiſhes as it were in old Age; ſometimes ſhe is bended into *Horns,* and then again ſhe appears like a half Circle; at other times ſhe looks Gibbous or Hump-backed, and immediately ſhe aſſumes a full globular Face; and afterwards by degrees ſhe diſappears and loſes all her Luſtre; ſometimes ſhe inlightens us the whole Night, at other times ſhe does not appear 'till late at Night: And even in a Total Eclipſe ſhe is frequently viſible, tho' with a very languid and pale Countenance; ſometimes ſhe keeps in the *Southern* Region of the Heavens; at other times, ſhe riſes high, and viſits the *Northern* Hemiſphere. All theſe Things were firſt found out by *Endymion* among the *Greeks,* who was the firſt among them who watched her Motions, and upon that Account was ſuppoſed to have fallen in Love with her.

The Moon *is a Spherical Opake Body.*

THE *Moon,* like the *Earth,* is a Dark, Opake, and Spherical Body; and only ſhines with the borrowed Light of the *Sun*: For it is the *Sun* who is the great Luminary in our Syſtem, and who always Illuſtrates that half of the *Moon*'s Body, which is turned towards him; whilſt the other half which is oppoſite, is involved in Darkneſs: But the Face of the *Moon,* that can be ſeen by the Inhabitants of the *Earth,* is that which is turned toward the *Earth*: And therefore according to the various Poſition of the *Moon,* in reſpect of the *Sun* and *Earth,* we do obſerve different Illuminations and degrees of Illuſtration; at one time a larger, at another a leſſer Portion of the illuminated Surface is to be ſeen; ſometimes there is no Part of it viſible, and ſometimes we obſerve the whole, and ſee the *Moon* with her Full Face. But for the better underſtanding of this matter, we will explain it by a Figure. Let S repreſent the *Sun,* T the *Earth,* R T S a Portion of the *Earth*'s Orbit, which it deſcribes in its Annual Courſe round

Plate V. Fig. 1, 2.

The true Motion of the Moon *from* Weſt *to* Eaſt.

round the *Sun.* Let ABCDEFG be the Orbit of the *Moon,* in which ſhe turns round the *Earth* in the ſpace of a Month, from the *Weſt* towards the *Eaſt.*

THIS Motion of the *Moon* is evident to our Senſes; for if the *Moon* be obſerved to arrive at the Meridian any Night with a *fixed Star,* the next Night ſhe will be 52 Minutes later in coming to the Meridian or in *Southing,* than the *Star,* ſhe having receded from the *Star* about 13 Degrees towards the *Eaſt.* Join the Centers of the *Sun* and *Moon* with the right Line SL, and thro' the Center of the *Moon* imagine a Plane MLN to paſs, to which the Line SL is Perpendicular: The Section of that Plane with the Surface of the *Moon,* will produce the Circle which bounds Light and Darkneſs in her; and ſeparates the inlightned Face from the Dark and obſcure ſide. In the ſame manner let the Centers of the *Earth* and *Moon* be joined by the right Line TL, which is Perpendicular to a Plane PLO paſſing thro' the Center of the *Moon*; that Plane will make on the Surface of the *Moon,* the Circle which diſtinguiſheth the viſible Hemiſphere, or that which is towards us, from the inviſible which is turned from us; which Circle may therefore be termed the *Circle of Viſion.*

The Circle in the Moon *bounding Light and Darkneſs.*

The Circle of Viſion.

The Phaſes of the Moon *explained.*

HENCE it is manifeſt that, whenever the *Moon* is in the Poſition A, in the Point of its Orbit oppoſite to the *Sun,* that then the Circle bounding Light and Darkneſs, and the Circle of Viſion do coincide; and that all the illuminated Face of the *Moon* will be turned towards the *Earth,* and be viſible by its Inhabitants: And then the *Moon* is ſaid to be Full, and ſhe Shines all Night long; and in reſpect to the *Sun* ſhe is ſaid to be in *Oppoſition*: For the *Sun* and *Moon* are ſeen in oppoſite Parts of the Heavens, the one riſing when the other Setts. When the *Moon* comes to B, the whole illuminated Disk MPN is not turned towards the *Earth,* there being a Part of it M P not to be ſeen by us; and then the *Viſible Illumination* will be deficient from a Circle, and the *Moon* will have a gibbous or Humped Form, ſuch as is marked in B. The *Moon* arriving at C, where the Angle C T S is nearly right, there only one half of the illuminated Disk is turned towards the *Earth*, and to be ſeen from thence; and then we obſerve a *Half-Moon* as in C, and ſhe is ſaid then to be *Biſected* or *Dichotomized*, that is cut in halfs. In this Situation the *Sun* and *Moon* are a fourth part of a Circle removed from each other, and the *Moon* is ſaid to be in a *Quadrate Aſpect*, or to be in her *Quadrature*. The *Moon* going forward to D, the illuminated Face MPN, has but a ſmall Portion of its ſelf turned towards the *Earth*, and the ſide of the Moon turned towards the *Earth* is for the greateſt part in Darkneſs: And therefore of the Spherical figure of the *Moon* which appears to us to be Plane, that ſmall Part which ſhines upon us will ſeem to be bended into narrow Points or Angles, and will look like what we call Horns; for there the Circle bounding Light and Darkneſs with the Circle of Viſion, doth form two ſmall Angles at their Interſections, and the *Phaſis* ſeen from the *Earth* will appear as in D. The *Moon* at laſt coming to E, will ſhew no part of its illuminated Face to the *Earth*, but all the dark ſide of the *Moon* will be turned towards it; and then the *Moon* diſappears, and ſhe is ſaid to be in *Conjunction* with the *Sun*, the *Sun* and ſhe being in the ſame Point of the Ecliptick. This Poſition we call *New Moon*. When the *Moon* advances further to F, ſhe again aſſumes a Horned or Crooked Figure; and as before the New *Moon* the Horns were turned *Weſtward*, ſo now after the time of New *Moon*, they change their Poſitions and look *Eaſtward*. When the *Moon* has proceeded to G, and is again in a *Quadrate Aſpect* with the *Sun*, ſhe will appear Biſected, and like a *Half-Moon*. In H ſhe will be bigger, but will ſtill be deficient from a whole Circle, and be ſeen Gibbous: But

The Gibbous Figure.

Half Moon, *or the* Moon *Dichotomized.*

The Quadrature.

New Moon, *or the* Conjunction.

But in A ſhe will again appear Circular, and in her full Splendor.

The Elongation *of the* Moon *from the* Sun.

THE Arch EL, or the Angle STL, contained under Lines drawn from the Centers of the *Sun* and *Moon* to the Center of the *Earth*, is called the *Elongation* of the *Moon* from the *Sun*. And the Arch MO, which is that Portion of the illuminated Circle MON which is turned towards the *Earth*, and which is the Meaſure of the Angle that the Circle bounding Light and Darkneſs and the Circle of Viſion make with one another, is every where nearly ſimilar to the Arch of Elongation EL, or, which is the ſame thing, the Angle STL is nearly equal to the Angle MLO, which I thus demonſtrate. Produce SL at pleaſure unto X, and the Angles TLP and MLS will be equal, they being both Right Angles: But the Angles OLS and PLX are alſo equal, becauſe they are Vertical to each other; therefore taking away thoſe equal Angles, the Angle MLO will remain equal to the Angle TLX; but the Angle TLX is the external Angle of the Triangle STL, and is therefore equal to both the inward and oppoſite Angles STL and TSL, by the 32d Propoſition of Book I of *Euclid*. But the Angle TSL is exceeding ſmall and next to nothing; for when biggeſt, in the Quadratures it does ſcarce exceed ten Minutes of a Degree; the Diſtance of the *Moon* from the *Earth* in compariſon of that of the *Sun* being ſo ſmall, that the Angle which it ſubtends at the *Sun* vaniſhes. And therefore the Angle STL by it ſelf, is nearly equal to the Angle MLO; whence the Arch MO will be ſimilar or like to the Arch EL.

THE Semicircle OMP, ſince its Plane paſſes thro' the Eye, will be projected into a Right Line, or appear like a Right Line on the Disk of the *Moon*; but the Circle bounding Light and Darkneſs in the *Moon*, ſince it is ſeen Obliquely from the *Earth*, will be projected into an Ellipſe, in which Form it will appear. Hence having the Elongation of the *Moon* from the *Sun*, it will be an eaſie matter to ſhew its *Phaſis*, or how it appears at that time. Let the Circle COBP repreſent the Disk of the *Moon* which is turned towards the *Earth*; and let OP be the Line in which the Semicircle OMP is projected, which ſuppoſe to be cut by the Diameter BC at Right Angles; and making LP the Radius, take LF equal to the Coſine of the Elongation of the *Moon* from the *Sun*: And then upon BC, as the great *Axis*, and LF the leſſer *Axis*, deſcribe the Semi-Ellipſe BFC. This Ellipſe will cut off from the Disk of the *Moon* the Portion BFCP of the illuminated Face, which is viſible to us from the *Earth*.

A Delineation of the Phaſis of the Moon, *for any Elongation.* Plate V. Fig. 3, 4, 5.

BY making LP the Radius, LF becomes the Coſine of the Elongation of the *Moon* from the *Sun*; PF in that caſe muſt be the Verſed Sine of the ſaid Elongation; and BFC (the Line which divides the illuminated and dark Parts of the Disk) will be an Ellipſe, whoſe greater *Axis* is the Diameter of the Disk BC, and half the leſſer *Axis* is the Semidiameter of the ſame Disk, diminiſhed by the Verſed Sine of the Elongation. Suppoſe now that OBPC were the Disk of the *Moon* turned towards the *Earth*, and BFC the Semi-Ellipſe dividing Light and Shadow: Draw any Line GHN parallel to the leſſer *Axis*, and which meets with the greater *Axis* in M, by the Nature of the Circle and the Ellipſe, LP will be to LF as GM is to MH; and by Diviſion of Ratio, LP is to PF as GM is to HG; and doubling of the Antecedents, PO will be to PF as GN is to GH. The ſame thing may be ſhewen of any other Line which is Parallel to the leſſer *Axis*, and therefore by the 12th Prop. Book V. Of *Euclid*, as PO is to PF ſo will all the Lines GN be to all the Lines GH. But all the Lines GN compoſe or make up the whole *Lunar* Disk, it conſiſting of an infinite number of Parallelograms, whoſe Heights are the Lines GN, and

The Quantity of Illuſtration.

and whoſe Baſes are indefinitely little: So likewiſe all the Lines GH make up that part of the Diſk which is illuminated.

AND therefore as PO is to PF, that is as the Diameter of a Circle, is to the verſed Sine of the *Moon*'s Elongation from the *Sun*; ſo is the whole Diſk of the *Moon*, to that part of it which is illuminated by the *Sun*. And hence the Illuſtration of the *Moon* at any time, is to its greateſt Illuſtration, which is at *Full Moon*, as the verſed Sine of the Elongation, is to the Diameter of a Circle.

The Earth *Illuminates the* Moon *by a Reflex light.*

AS the *Moon* by reflected Light from the *Sun* illuminates the *Earth*, ſo the *Earth* does more than repay her kindneſs, in enlightning the Surface of the *Moon*, by the *Sun*'s reflex Light, which ſhe diffuſes more abundantly upon the *Moon*, than the *Moon* does upon us: For the Surface of the *Earth* is above fifteen times greater than that of the *Moon*; and therefore if both Bodies have the ſame power in Reflecting in proportion to their bigneſs, the *Earth* would ſend back fifteen times more Light to the *Moon*, than it receives from it. For the *Earth* appears fifteen times bigger to the Inhabitants of the *Moon*, than the *Moon* does to us. In new *Moons* the Illuſtrated ſide of the *Earth*, is fully turned towards the *Moon*, and will therefore at that time illuminate the dark ſide of the *Moon*; and then the *Lunarians* will have a *Full Earth*, as we in a ſimilar Poſition have a *Full Moon*. And from thence ariſes that dim Light which is obſerved in the Old and New *Moons*, whereby beſides the bright and ſhining Horns, we can perceive the reſt of her Body behind them, tho' but dark and obſcure. Now when the *Moon* comes to be in *Oppoſition* to the *Sun*, the *Earth* ſeen from the *Moon* will appear in *Conjunction* with him, and its dark ſide will be turned towards the *Moon*, in which Poſition the *Earth* will diſappear; after the ſame manner as the *Moon* does diſappear to us in the time of *New Moon*, or her in *Conjunction* with the *Sun*. After this the *Earth* will appear to the Inhabitants of the *Moon* in a Horned Form. In a Word the *Earth* will ſhew all the ſame Appearances to the Inhabitants of the *Moon* as the *Moon* does to us.

The Periodical Month, and the Synodical.

ALTHO' the *Moon* circulating round the *Earth* deſcribes its Orbit in the Space of 27 Days and ſeven Hours, which ſpace of Time is called a Periodical Month; yet the time the *Moon* takes to go from one Conjunction to the next, which is a Synodical Month or a *Lunation*, is greater than the Periodical. For while the *Moon* in its proper Orbit finiſhes its Courſe, the *Earth*, with this her Companion and its Orbit, are going on their way round the *Sun*, and are advanced almoſt a whole Sign towards the *Eaſt*; ſo that the Point of the Orbit which in the former Poſition was placed in a Right Line joining the Centers of the *Earth* and *Sun*, is now more *Weſterly* than the *Sun*: And therefore when the *Moon* has again arrived to that Point, it will not yet be ſeen in Conjunction with the *Sun*.

Plate V. Fig. 6.

FOR let AB repreſent a Portion of the Orbit of the *Earth*, and when the *Earth* is in T, ſuppoſe the *Moon* in L, in Conjunction with the *Sun* in S: while the *Moon* leaves the Point L, and proceeds in deſcribing its Orbit LACD; the *Earth* in the mean time by its Motion round the *Sun* is carried in the Arch T*t*, and when it is come to *t*, the Orbit of the *Moon* is in the Poſition *lacd*, and the Point of the Orbit L will now be in the Line *tl*, which is Parallel to the former Line TL: Hence it is plain, that when the *Moon* has come to *l*, and deſcribed its whole Orbit, that it is not then arrived at a Conjunction with the *Sun*, but it muſt ſtill go further and move thro' the Arch *l*M, before it can get between the *Earth* and *Sun*: And ſince the *Moon* finiſhes her Courſe in the ſpace of 27 Days, in that time the *Earth* will have compleated an Arch of 27 Degrees in the Ecliptick; now the Arch *l*M and T*t* are alike or ſimilar, becauſe the Lines

L T, and *l t*, being Parallel, the Angles *l t* M and L S M are equal. But indeed it is required that the *Moon* ſhould deſcribe a greater Arch than *l* M, before it gets between us and the *Sun*, becauſe the *Earth* is ſtill moving on in the mean time: And therefore the whole *Lunation*, or time from *New Moon* to *New Moon*, is not finiſhed but in the ſpace of 29 Days and a half; And the *Moon* does every Day recede from the *Sun*, about 12 Degrees and ſome odd Minutes, which is called the diurnal Motion of the *Moon* from the *Sun*.

The diurnal Motion of the Moon *from the* Sun.

IF the Plane of the *Moon*'s Orbit coincided with the Plane of the Ecliptick, that is, if the *Earth* and *Moon* moved both in the ſame Plane, the way of the *Moon* in the Heavens ſeen from the *Earth*, would be exactly the ſame with the Circle the *Sun* is ſeen to deſcribe; only the *Sun* would be obſerved to deſcribe that Circle in the ſpace of a Year, which the *Moon* does in a Month. Now in reality the Plane in which lies the *Moon*'s Orbit, is not coincident with the Plane of the Ecliptick: but theſe two Planes cut one another in a Right Line, which paſſes thro' the Center of the *Earth*; and they are inclined to one another in an Angle of about five Degrees.

Plate V. Fig. 7.

LET A B be a Portion of the *Earth*'s Orbit, T the *Earth*, and let the Circle C E D F repreſent the Orbit of the *Moon*, in which is the Center of the *Earth*: with the ſame Center T, in the Plane of the Ecliptick, let there be deſcribed another Circle C G D H, whoſe Semidiameter may be equal to the Semidiameter of the *Moon*'s Orbit; theſe two Circles being in different Planes, and having the ſame Center T, will interſect each other in a Line D C, which paſſes thro' the Center of the *Earth*; and C E D, one half of the Orbit of the *Moon*, will riſe above the Plane of the Circle C G H, towards the *North*. The other half of the Orbit D F C will be depreſſed below it, towards the *South*. The Right Line D C wherein the

The Moon *does not move in the Ecliptick.*

the two Circles cut one another, is called the Line of the *Nodes*; and the Points of the Angles C and D are called the *Nodes.* And the *Node* C, where the *Moon* aſcends *Northward* above the Plane of the Ecliptick, is called the *Aſcending Node*, and the *Head of the Dragon*, and is thus Marked ☊. The other D, from whence the *Moon* deſcends to the *South*, is named the *Deſcending Node*, and the *Tail of the Dragon*, which by the *Aſtronomers* is marked in this manner ☋. If the Line of the *Nodes* were immoveable, that is if it had no other Motion than that whereby it is carried round the *Sun*, it would always look to the ſame Point of the Ecliptick; that is, it would always keep Parallel to it ſelf, as we ſhewed the *Axis* of the *Earth* ought to do: But we find by Obſervation that this Line of the *Nodes* does conſtantly change its Place, and ſhifts its Situation from *Eaſt* to *Weſt*, contrary to the Order of the Signs; and by a Retrograde Motion finiſhes its Circulation in the compaſs of almoſt 19 Years: After which time either of the *Nodes* having receded from any Point of the Ecliptick, returns to the ſame again. And when the *Moon* is in the *Node*, ſhe is alſo ſeen in the Ecliptick.

The Line of Nodes.

The Aſcending Node, *or the* Dragon's *Head.*

The Deſcending Node, *or the* Dragon's *Tail.*

The Retrograde *Motion of the* Nodes.

HENCE it is evident, that the *Moon* can never be obſerved preciſely in the Ecliptick, but twice in every Period, that is when ſhe enters the *Nodes*; when ſhe is in any other place of her Orbit, ſhe deviates from it, and is ſometimes nearer, ſometimes further removed from the Ecliptick, according as ſhe happens to be nearer, or further off from the *Nodes:* But ſhe is at her greateſt Diſtance from the *Nodes*, when ſhe is in the Points of her Orbit E or F, which are the middle Points between the *Nodes*; and theſe Points are called the *Limits.* The Diſtance of the *Moon* from the Ecliptick is called her *Latitude*, which is meaſured by an Arch of a Circle drawn thro' the *Moon*, Perpendicular to the Ecliptick; the Arch of this Circle intercepted

The Limits.

The Moon's Latitude.

between the *Moon* and the Ecliptick, meaſures the *Moon*'s *Latitude*, or her Diſtance from the Ecliptick: And therefore ſuch Circles perpendicular to the Ecliptick, are called Circles of *Latitude*; the *Latitude* of the *Moon* when it is at the biggeſt, as in E or F, does never exceed five Degrees and about eighteen Minutes, which *Latitude* is the Meaſure of the Angles at the *Nodes*.

LECTURE X.

Of the Inequalities in the Lunar *Motions. The Face of the* Moon, *her Mountains and Vallies.*

The Orbit of the Moon *an Ellipſe.*

OBSERVATIONS have diſcovered to us that the Diſtance of the *Moon* from the *Earth* does conſtantly change; ſometimes the *Moon* comes nearer to us, ſometimes goes further from us; the reaſon of which is becauſe the *Moon* does not move in a circular Orbit, which has the *Earth* for its Center: But the real Orbit of the *Moon* is of an Elliptick Form, ſuch as is repreſented in the Figure A B P D, one of whoſe *Focus*'s is always the Center of the *Earth*; A P is the greater *Axis* of the Ellipſe and the Line of the *Apſides*; T C is the Eccentricity, the Point A which is the higheſt *Apſis*, is called the *Apogeon* of the *Moon*; the loweſt *Apſis* which is the Point P, is called the *Perigeon*, in which the *Moon* comes neareſt the *Earth*. And if the Orbit of the *Moon* had no other Motion beſides that wherewith it is carried round the *Sun*, it would always

Plate VI. Fig. 1.

The Moon's Apogoen *and* Perigeon.

Plate V

front. p. 100

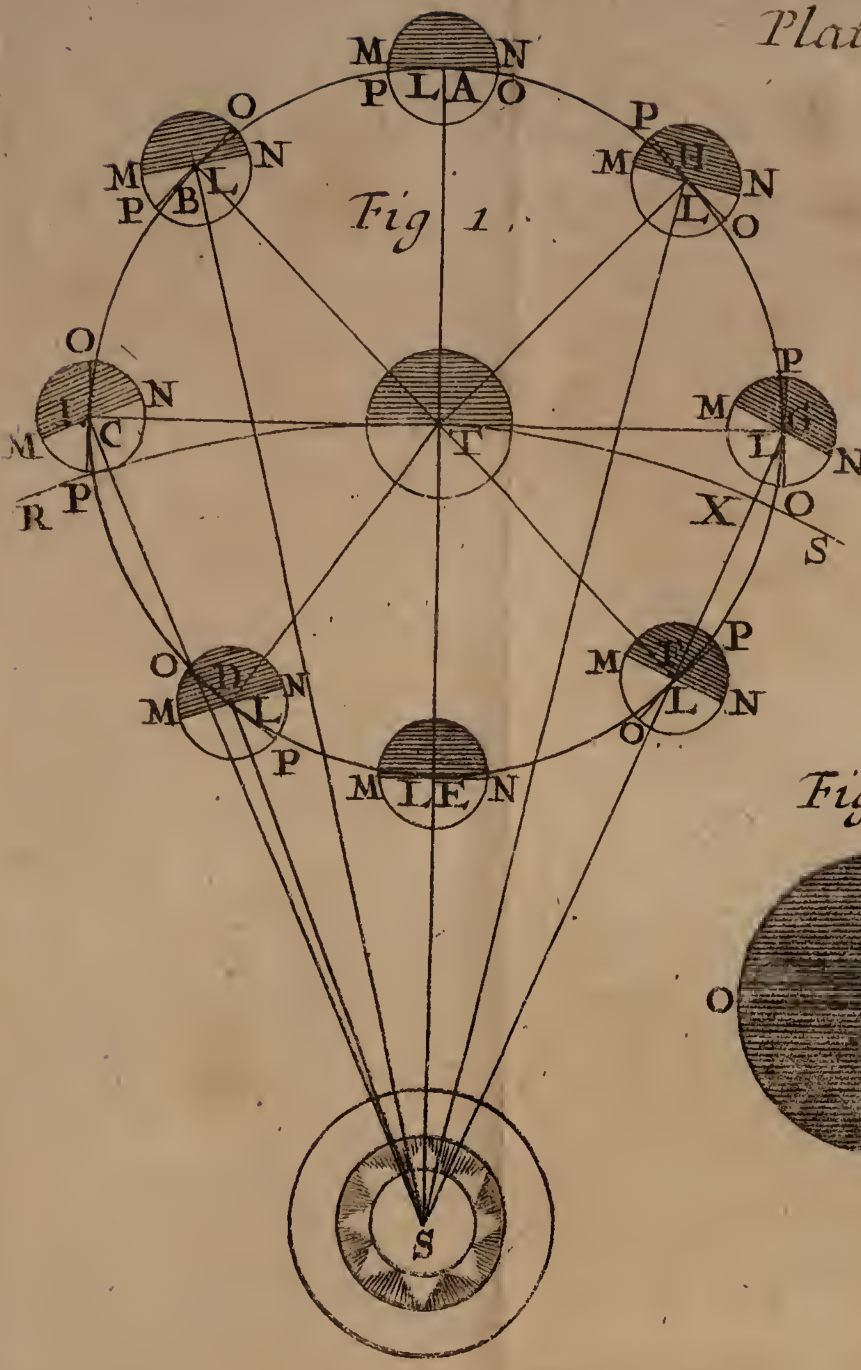


Fig 1.

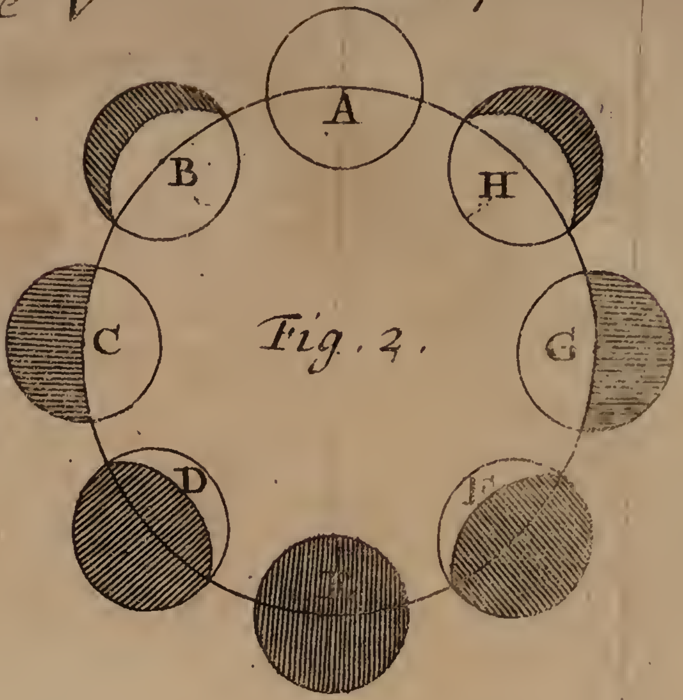


Fig. 2.

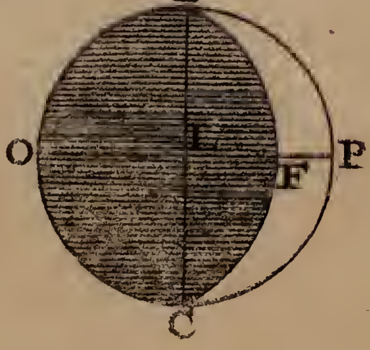
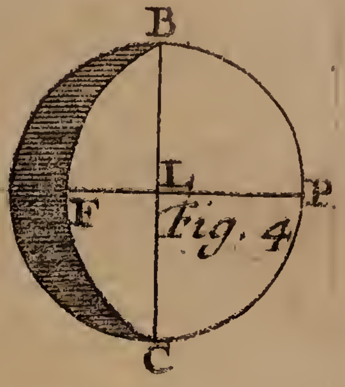


Fig. 3.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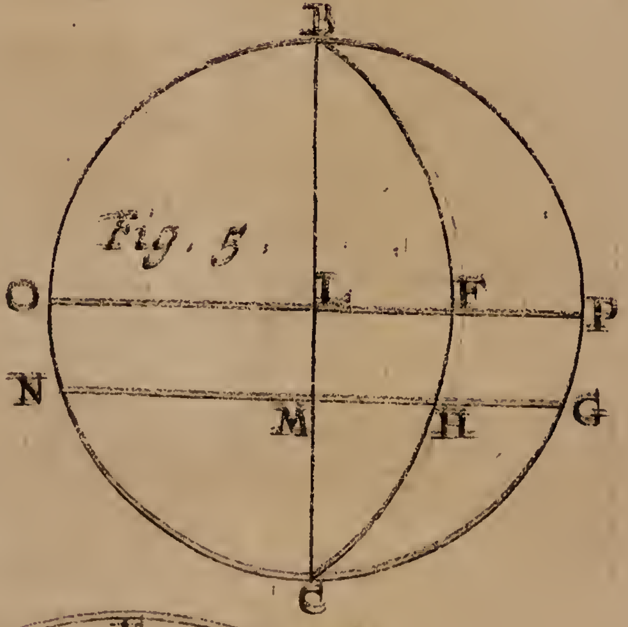
Fig. 5.

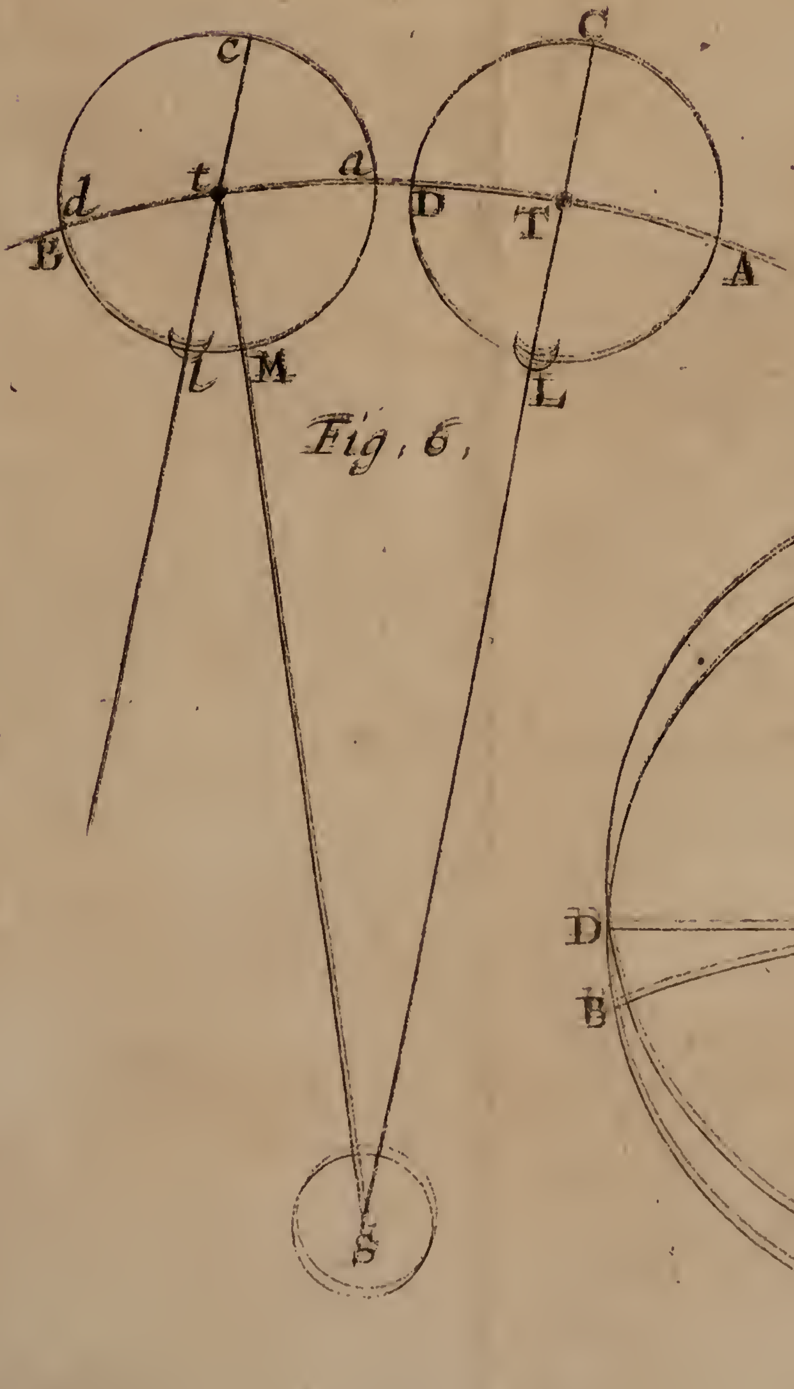
Fig. 6.

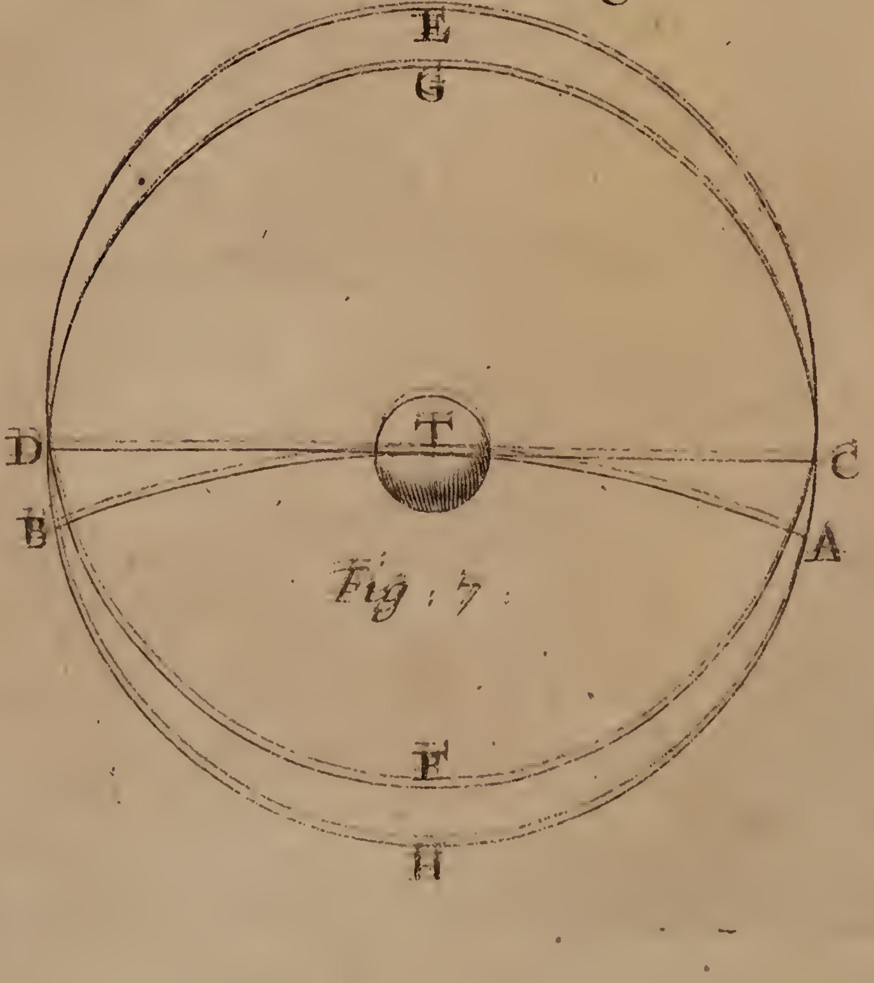
Fig. 7.

ways retain a Poſition parallel to it ſelf, and would always point the ſame way, and be obſerved in the ſame Point of the Ecliptick; and whenever the *Moon* came to that Point, it would conſtantly be at the ſame Diſtance from us: But this Line of the *Apſides* is likewiſe obſerved to be moveable, and to have an Angular Motion round the *Earth* from the *Weſt* towards the *Eaſt*, according to the Order of Signs, ſo that it does not return to the ſame Situation, 'till after the ſpace of almoſt nine Years.

The Inequalities of the Motions of the Moon.

THE Motions of the *Moon*, and that of her Orbit, do not obſerve the ſame Inequalities. For firſt, when the *Earth* is in her *Aphelion*, at the greateſt Diſtance from the *Sun*, the *Moon* being ſo likewiſe, the *Moon* does ſomewhat quicken her pace, and performs her Circulation in leſs time. On the contrary, when the *Earth* approaches nigheſt to the *Sun* in the *Perihelion*, the *Moon* is likewiſe nearer, and then ſhe ſlackens her Motion: Upon which Account it is that the *Moon* revolves about the *Earth* in ſhorter time when the *Earth* is in her *Aphelion*, than when ſhe is in her *Perihelion*; ſo that the Periodical Months are not all equal.

Syzygia.

Secondly, When the *Moon* is in the *Syzygia*, that is, in the Line which joins the Centers of the *Earth* and *Sun* (which may be either in her Oppoſition or Conjunction) all other things being alike, ſhe has a ſwifter Motion round the *Earth*: But in the Quadratures ſhe goes ſlower.

Thirdly, According to the different Diſtance of the *Moon* from the *Syzygia*, that is from Oppoſition or Conjunction, ſhe changes her Motion; and in the firſt Quarter of her Motion, that is from Conjunction to her firſt Quadrature, ſhe loſes ſomething of her ſwiftneſs; in her ſecond Quarter, from the Quadrature to her Oppoſition, ſhe encreaſes in Velocity: In her third Quarter from Oppoſition to the laſt Quadrature, ſhe again loſes of her Motion; and from that Quadrature to the Conjunction, ſhe again recovers her ſwiftneſs. This Inequality in the *Moon*'s Motions was firſt diſcovered by the Noble *Tycho*, who called it the *Moon*'s *Variation.*

The Variation.

Fourthly, The *Moon* moves in an Ellipſe, whoſe *Focus* is in the Center of the *Earth*, round about which ſhe deſcribes *Area's* proportional to the Times, as the Primary *Planets* do round the *Sun*; whence the Motion of the *Moon* muſt be quickeſt in the *Perigeon*, and ſloweſt in the *Apogeon.*

The Orbit of the Moon, *and its Excentricity changeable.*

Fifthly, The very Orbit of the *Moon* is changeable, and does not always keep the ſame Figure; but its Excentricity does now and then grow greater, and now and then it diminiſhes: And it is greateſt when the Line of the *Apſides* is coincident with the *Syzygia*, or is in the Line which joins the Centers of the *Sun* and *Earth*: And the Excentricity is the leaſt when the Line of the *Apſides* cuts the other at Right Angles. The difference between the greateſt and leaſt Excentricity is ſo conſiderable, that it exceeds the half of the leaſt Excentricity.

The Apogeon *has an unequable Motion.*

Sixthly, The very *Apogeon* of the *Moon* has an unequal Motion, and ſometimes moves forward, and ſometimes backwards: when it is coincident with the *Syzygial* Line, its Motion is forward; but when it cuts that Line at Right Angles, its Motion is backwards, and its progreſs, and regreſs are no ways equal. But when the *Moon* is in her Quadratures with the *Sun*, the *Apogeon* goes but ſlowly forward, or even may ſtand ſtill, or go backwards. But when the *Moon* comes to be Oppoſite or conjoined to the *Sun*, the *Apogeon* has a quick Motion forward.

Seventhly, The Motion of the *Nodes* is not at all uniform, for when the Line of the *Nodes* coincides with the Line of the *Syzygia*, then they ſtand ſtill without any Motion; but when they cut that Line at Right Angles, they go backwards, or from *Eaſt* to *Weſt* with a conſiderably quick Motion. The moſt ſagacious *Sir* ISAAC NEWTON was the firſt, and the only Man, who has diſcovered the true Cauſes of all theſe Inequalities; and has demonſtrated that they all ariſe according to the Laws of Mechaniſm, from the *Theory of Gravitation* of Matter to Matter: It is very ſurpriſing that the *Moon*, which of all the Heavenly Bodies is neareſt to us, ſhould be of ſuch difficult Acceſs; and that it ſhould be ſo hard to find out her Ways, and the Cauſes of all her Irregularities.

The Moon *moves uniformly about her* Axis.

THE only equal Motion of the *Moon* is that, wherewith ſhe turns round her *Axis* in the ſame time that ſhe moves round us in her Orbit, from whence it comes to paſs, that ſhe always keeps the ſame Face towards us. But this very equability in Rotation, is the Cauſe of an apparent Inequality; that the *Moon* appears to librate about its *Axis* ſometimes from the *Eaſt* to the *Weſt*, and now and then from the *Weſt* to the *Eaſt*; and that ſome Parts in the *Weſtern* Limb or Margin of the *Moon* recede from the Center of the Disk, and ſometimes they move towards it. Some of theſe Parts which were before viſible, ſet and hide themſelves in the inviſible ſide of the *Moon*, and afterwards become again conſpicuous. Such a Motion in the *Moon* is called her *Libration*, and it ariſes from the unequal Motion of the *Moon* in the Perimeter of her Orbit: For if the *Moon* moved in a Circle, whoſe Center coincided with the Center of the *Earth*, and turned round its *Axis* in the preciſe time of its Period round the *Earth*; in that caſe the Plane of the ſame *Lunar* Meridian would always paſs thro' the *Earth*; and the ſame Face of the *Moon* would be conſtantly and exactly turned towards us. But ſince the real Motion of the *Moon* is in an Ellipſe, in whoſe *Focus* is the *Earth*, and the Motion of the *Moon* about her *Axis* is equable; or which is the ſame thing, every Meridian of the *Moon* by this Rotation deſcribes Angles proportional to the Times, the Plane of no one Meridian will conſtantly paſs thro' the *Earth*.

The Moon's Libration.

Lecture X.

Plate VI. Fig. 2.

FOR let ALP be the Orbit of the *Moon*, in whoſe *Focus* is the *Earth* in T, and when the *Moon* is in A, its Meridian MN produced will paſs thro' the *Earth*: And if the *Moon* only revolved in her Orbit, without any Motion round an *Axis*, the ſame Meridian MN would always keep a Poſition parallel to it ſelf; ſo that when the *Moon* comes to L, the Meridian MN would be in the Poſition PQ which is parallel to MN, but on the account of the *equable Rotation*, the Meridian MN changes its Situation, and deſcribes Angles proportional to the Times; ſo that in the Periodical time of the *Moon*'s Revolution round the *Earth*, it deſcribes four Right Angles; and therefore in L it will have the Poſition mLn; ſuch that the Angle QLn may have the ſame proportion to a Right Angle, as the Time the *Moon* takes to deſcribe the Arch AL, has to a fourth part of the Periodical time. But the time the *Moon* takes to deſcribe the Arch AL, is to the fourth part of the Periodical time, as the *Area* ATL is to the *Area* ACL, that is to $\frac{1}{4}$ part of the *Area* of the Ellipſe: Therefore the Angle QLn will be to a Right Angle in the ſame proportion. But the *Area* ATL is greater than the *Area* ACL, or than the fourth part of the *Area* of the Ellipſe: The Angle therefore QLn will be bigger than a Right, or bigger than QLC; but QLC is bigger than QLT, wherefore QLN will be much bigger than QLT. The Meridian therefore MN, whoſe Plane paſſed thro' the *Earth*, when the *Moon* was in A, now the *Moon* is arrived at L, does not look towards the *Earth*: And therefore the Hemiſphere of the *Moon* which is towards the *Earth*, the *Moon* being at L, is not the ſame with that which was towards the *Earth* when the *Moon* was in A; and thoſe Parts of the *Moon*'s Surface beyond Q, will come under Obſervation, which before, when the *Moon* was in A, were not to be ſeen, being in the ſide of the *Moon* quite oppoſite to us. But as ſoon as the

Moon arrives at her *Perigeon* P, then the Meridian MN has deſcribed in its Rotation a Semicircle; and then again its Plane paſſes thro' the *Earth*, and the former Point N will be directly towards us, and be in the Center of the Disk. Hence it is evident that this *Libration* of the *Moon* is reſtored twice in each Period of the *Moon*, that is when ſhe comes to her *Apogeon* and *Perigeon*.

The Surface of the Moon *Rugged and Mountanous*

IF the Surface of the *Moon* were ſmooth and poliſhed like a Looking Glaſs, it would not then reflect Light upon all ſides and every way; but it would ſhew us only in ſome Poſitions the Image of the *Sun*, no bigger than a Point, but with an immenſe Luſtre. But as in all our *Earthly* Bodies, ſo in the *Moon*, its Surface is very rough and uneven; upon which account it diffuſes the Light by reflecting it to all ſides, without producing any Image of the *Sun*, as poliſhed Glaſſes do.

A Demonſtration that there are Mountains in the Moon.

BUT the Surface of the *Moon* is not only rough and uneven, but there are upon it moſt prodigious high Mountains, and deep Vallies, which cover the whole Face of the *Moon*: This we thus prove. If there were no Parts in the *Moon* higher than the reſt, no Prominent Points, then a Right Line in the *Dichotomy* or Quadrature, and an Elliptick Line in all the other *Phaſes* would terminate the light and dark parts of the Disk: But when the *Moon* is viewed with a Teleſcope, we find that there is no regular Line which ſeparates Light and Darkneſs in the *Moon*'s Surface, but the Confines of theſe Parts appear as it were toothed, and cut with innumerable Notches and Breaks; and even in the dark Part, near the Borders of the lucid Surface, there are ſeen ſome ſmall Places enlightned by the *Sun*'s Beams: And upon the fourth Day after *New Moon*, there may be perceived ſome ſhining Points, like Rocks or ſmall Iſlands, within the dark Body of the *Moon*; but not far from the Confines of Light and Darkneſs, there are obſerved other little Spaces which join to the enlightned Surface, but run out into the dark ſide; which by degrees change their Figure, 'till at laſt they come wholly within the illuſtrated Face, and have no dark Parts round them: Afterwards we obſerve many more ſhining Spaces to ariſe by degrees, and to appear within the dark ſide of the *Moon*, which before they drew near to the confines of Light and Darkneſs, were inviſible; being without any Light, but wholly immerſed in the Shadow. The contrary is obſerved in the Decreaſing *Phaſes*, where the lucid Spaces which joined the illuminated Surface, by degrees recede from it; and after they are ſeparated quite from the Confines of Light and Darkneſs, remain for ſometime viſible, 'till at laſt they alſo diſappear: Now it is impoſſible that this ſhould be, unleſs theſe ſhining Points were higher than the reſt of the Surface, ſo that the light of the *Sun* may reach them.

In the Moon *large Cavities and Pits.*

THESE ſhining Points ſituated in the *Moon*'s Surface, without the Confines of the illuminated Surface, are the Tops of very high Mountains, which riſing far above the other Parts of the Surface, are ſooner reached by the *Sun*'s Beams, and remain longer in the Light, than the reſt of the Parts do which are lower. Beſides theſe, we likewiſe obſerve, even in the illuminated Face of the *Moon*, many dark and obſcure Spots, which ſeem to be only Caverns, or large Cavities; on which the *Sun* ſhining very obliquely, and touching only their upper edge with his Light, the deeper places remain without Light: But as the *Sun* riſes higher upon them, they receive more Light, and the Shadow or dark Parts grows ſmaller and ſhorter, 'till the *Sun* comes at laſt to ſhine directly upon them; and then the whole Cavity will be illuſtrated, and the Parts which were obſcure before, will then look as bright as the Tops of the Mountains. From theſe conſtant Obſervations it is plain to a demonſtration, that the *Moon*'s Face is covered with Mountains in ſome places, and that in others it is cut with deep Pits and Caverns.

The Lunar Mountains higher than the Mountains of the Earth.

Plate VI. Fig. 3.

THE *Lunar* Mountains are much higher in proportion to the Body of the *Moon*, than any Mountain upon our Globe; for the *Geometers* can take the Height of them as eaſily as he can find the Meaſure of a Mountain upon our *Earth*: The way of finding the Height of a *Lunar* Mountain is this, Let E G D be the Hemiſphere of the *Moon* illuminated by the *Sun*, and E C D the Diameter of the Circle bounding Light and Shadow, A the Top of a Hill, within the dark Part when it firſt begins to be illuminated. Obſerve with a Teleſcope the Proportion of the Right Line A E, or the Diſtance of the Point A from the lucid Surface, to the Diameter of the *Moon* E D; and becauſe in this caſe the Ray of light E S touches the Globe of the *Moon*, A E C will be a Right Angle, by the 16th *Prop.* Book third of *Euclid*: And therefore having in the Triangle A E C, the two ſides A E and E C, we can find out the third ſide A C, from which ſubducting B C, or E C, there will remain A B, the Height of the Mountain. *Ricciolus* affirms, that upon the fourth Day after *New Moon*, he has obſerved the Top of the Hill called St. *Katherin* to be illuminated, and that it was diſtant from the Confines of the lucid Surface, about a ſixteenth part of the *Moon*'s Diameter, or an eighth part of her Semidiameter. And therefore if C E be 8, A E will be 1; and the Square of A C will be equal to the Squares of C E and E A, by *Prop.* 47, Book firſt of *Euclid*. Now the Square of C E being 64, and the Square of A E being 1, the Square of A C will be 65, whoſe Square Root is 8,062 which expreſſes the length of A C: From thence deducting B C = 8, there will remain A B = 0,062. So that C B or C E is therefore to A B, as 8 is to 0,062; that is, as 800 to 62: And therefore ſince the Semidiameter of the *Moon* is 1182 Miles; if we make the proportion as 800 to 62, ſo 1182 is to 9; we ſhall have 9 Miles for the Height of that Mountain, which is therefore three times higher than the Tops of our higheſt Hills on *Earth*.

A method of Meaſuring them.

Great varieties to be obſerved in the Face of the Moon.

WHOEVER ſhall Contemplate the Face of the *Moon* with a Teleſcope, will diſcern it diſtinguiſhed with an admirable variety of Spots ſome Parts have a moſt bright Luſtre, and ſome *Philoſophers* have imagined them to be Rocks of Diamonds; others have compared them to Pearls, or ſome precious Stones: But they ſeem to be the Solid parts of high Mountains, which are endued with a quality whereby they ſtrongly reflect the Light. There are again other Places and Parts of the *Moon*'s Face, and they are not a few nor ſmall, which look dark, and of a duskiſh Colure, which the *Philoſophers* have fancied to be Seas, Lakes, and Fens: But yet we find that they cannot be Seas, nor any thing of a Liquid ſubſtance, for when they are looked at with a good Teleſcope, we find they conſiſt of an infinity of Caverns and empty Pits, whoſe Shadows fall within them; which can never be in a Sea or liquid Body. Theſe black Spots therefore cannot poſſibly be Seas: But they conſiſt of ſome darker and ſad coloured Matter, which does not reflect the Light ſo ſtrongly as the Solid and ſhining Mountains do. But even within theſe dark Spots we obſerve ſome Bodies of a brighter Light, wherewith they out-ſhine the reſt.

There are no Seas.

No Clouds.

THERE ſeems to be no Clouds nor Vapours in the *Moon*, from whence Rain may be generated: For ſuch Clouds would ſometimes cover the Face of the *Moon*, and hide ſome of its Regions from our ſight, which we never obſerve them to do: But in the *Moon* there is a conſtant Serenity, without any dark Weather; and when there are no Clouds in our Air, the *Moon* conſtantly appears with the ſame Luſtre. It is probable likewiſe that the *Moon* has no Atmoſphere to ſurround it. For the *Planets* and *Stars*, which ſometimes are ſeen very near its Limb, have not their Light refracted, as it is when it paſſes thro' our Atmoſphere.

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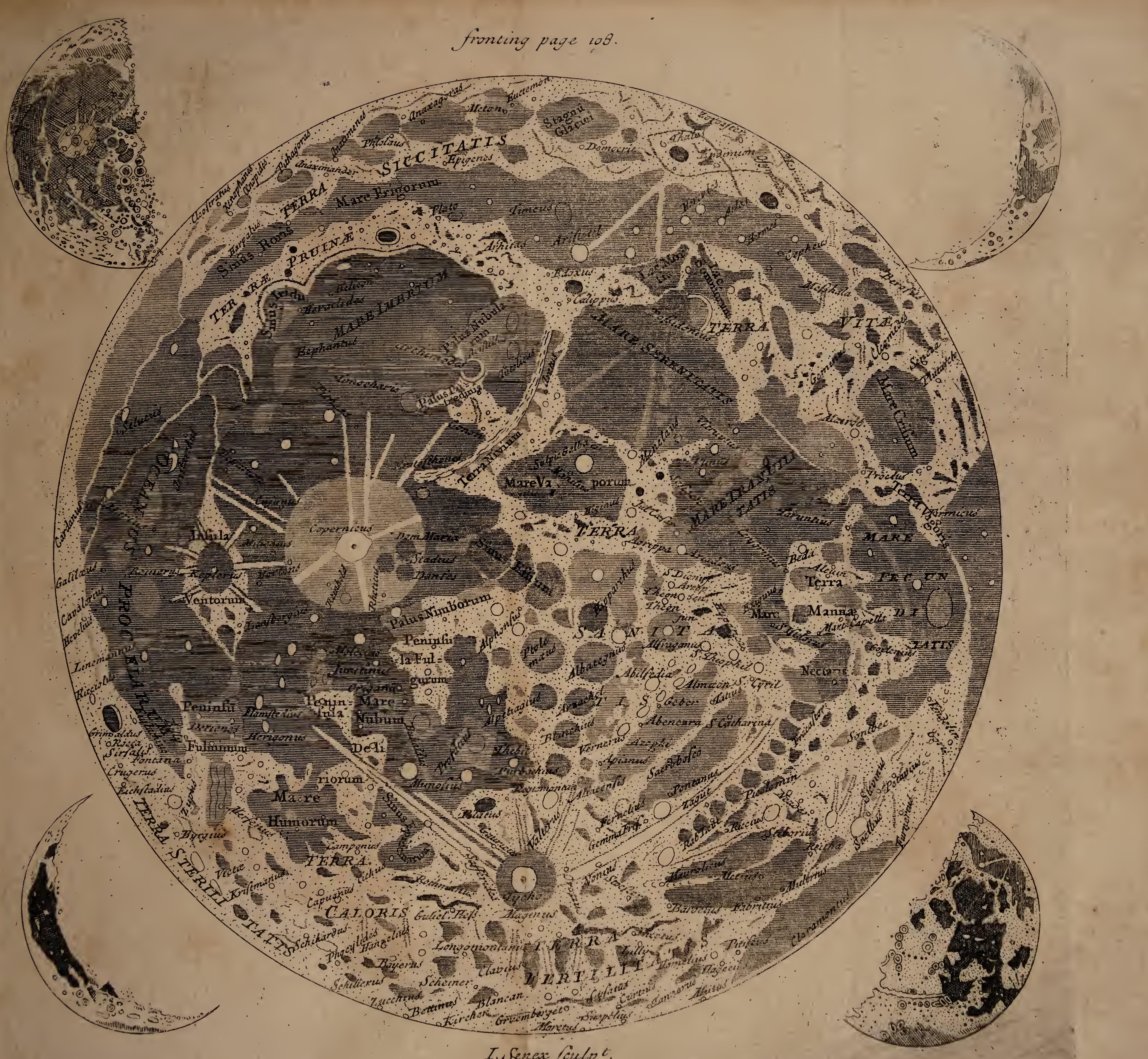

I. Senex ſculp^{t}.

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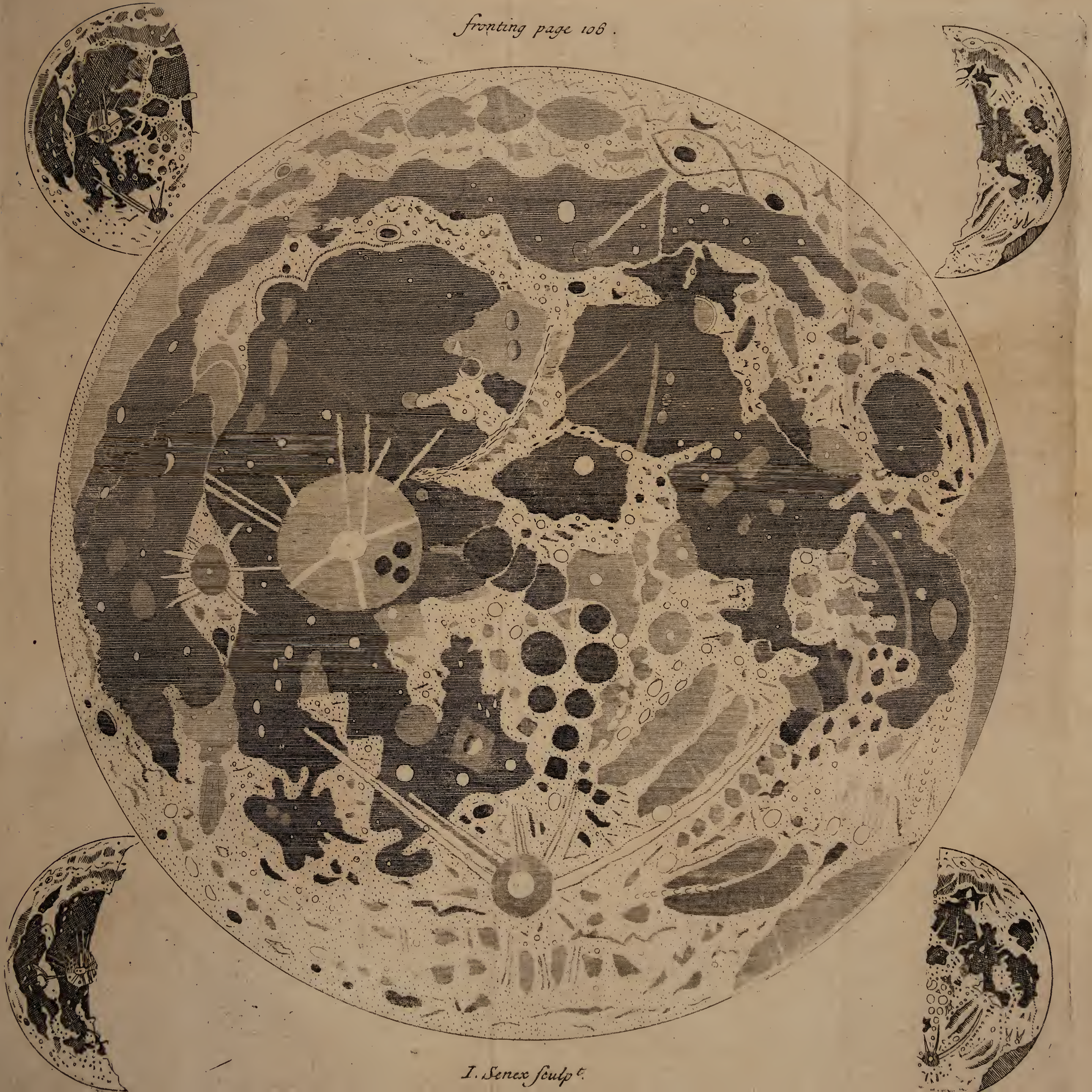


I. Senex ſculpt.

THE *Aſtronomers* have drawn the Face of the *Moon*, according as it is ſeen with the beſt Teleſcopes, for which we are obliged to the accurate Labours of theſe Famous Selenographers *Florentius Langrenus*, *John Hevelius* of *Dantzig*, *Grimaldus* and *Ricciolus*, *Italians*; who have taken particular Care to note all the ſhining Parts of the *Moon*'s Face, and for the better diſtinguiſhing them, they have given to each Part a proper Name. *Langrenus* and *Ricciolus* have divided the *Lunar* Regions among the *Philoſophers* and *Aſtronomers*, and other eminent Men: But *Hevelius* fearing leaſt the *Philoſophers* ſhould quarrel about the Diviſion of the Lands, has ſpoiled them of this their Property; and gives the Parts of the *Moon* thoſe *Geographical* Names that belong to the different Iſlands, Countries and Seas of our *Earth*, without any regard to Situation or Figure.

The Selenographers or Aſtronomers *who have deſcribed the* Moon's *Surface.*

LECTURE XI.

Of the Obſcurations or Eclipſes *of the* Sun *and* Moon.

THERE is nothing in *Aſtronomy* which ſhews the great Sagacity of Human Underſtanding, and its deep Penetration, more than a clear Explication of the ſuddain Diſappearings of the *Sun* and *Moon*, that is, of their *Eclipſes*; and the accurate Predictions when they are to come to paſs, which the *Aſtronomers* can now foretel almoſt to a Minute. Tho' this be the niceſt and moſt ſubtle Speculation of our Science, yet it is certain and undoubtable, than which nothing can be more Sublime, or worthy of our Contemplation.

An Eclipſe what.

The word Eclipſe is derived from the *Greek* ἐκλείπω, which ſignifies to Faint, or to Swoon away: So Sick and dying Perſons when a ſwooning Fit, and a Death-like faintneſs comes over them, were ſaid by the *Greeks* to fall into an Eclipſe: After the ſame manner the *Moon*, when ſhe Shines with a full Face, if ſhe falls into the Shadow of the *Earth*, does loſe the enlivening Beams of the *Sun*'s light, and grows Pale as if ſhe were about to Dye. And the *Sun* again when the *Moon* interpoſes her Body, and deprives us of his Heat and Light; tho' in himſelf he retains his Luſtre, yet to us he ſeems to vaniſh and grow dark. At ſuch times the *Sun* and *Moon* are ſaid to ſuffer and fall into an Eclipſe. Theſe Eclipſes muſt be here Explained: and that we may begin from the firſt Principles.

A Shadow what.

IT is to be obſerved that all Opake and dark Bodies, when they are expoſed to the direct light of the *Sun*, caſt a Shadow behind them, that is oppoſite to the Line the *Sun* is in. This Shadow is nothing but the loſs or Privation of light in the Space oppoſite to the *Sun*, by reaſon the *Sun*'s Rays are intercepted by the opake Body. Now ſince the *Earth* is an opake Body, it muſt likewiſe caſt a Shadow towards the Space oppoſite to the *Sun*; in which Space if the *Moon* ſhould come, it muſt neceſſarily be darkned, and loſe the Light which it had before from the *Sun*. And becauſe the Figure of the *Earth* is Spherical, the figure of the Shadow would be Cylindrical, if the *Earth* and *Sun* were of equal bigneſs; or if the *Earth* were bigger than the *Sun*, the Shadow would have the figure of a Cone which had loſt a peice at his Top or Vertex; and the farther it were extended, would grow thicker and thicker.

Plate VI. Fig. 4, 5, 6.

The figure of the Shadow.

AND in both theſe Caſes, the Shadow would run out into infinite Space, without ever having an end: And then it would involve ſometimes the other *Planets*, *Mars*, *Jupiter* and *Saturn*, within

Plate VI *front. p. 110.*

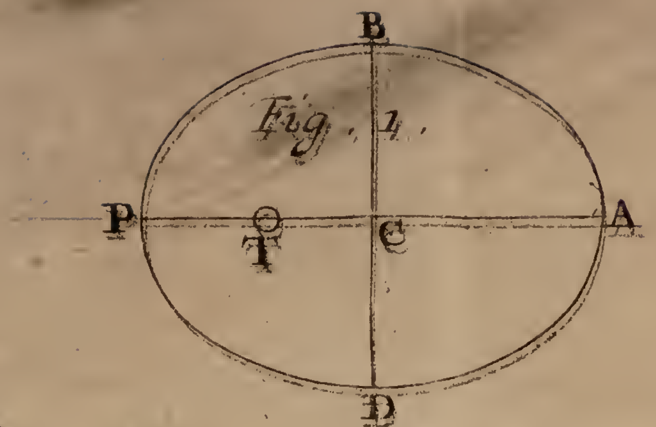


Fig. 1.

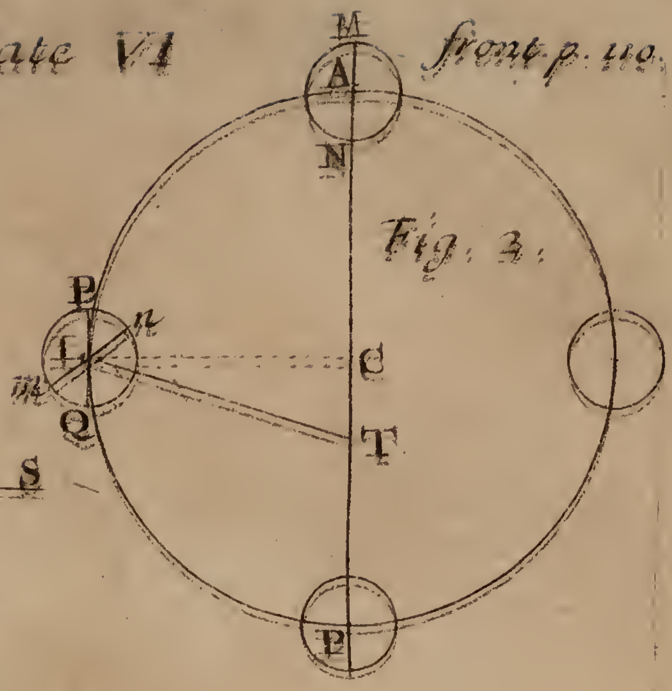


Fig. 2.

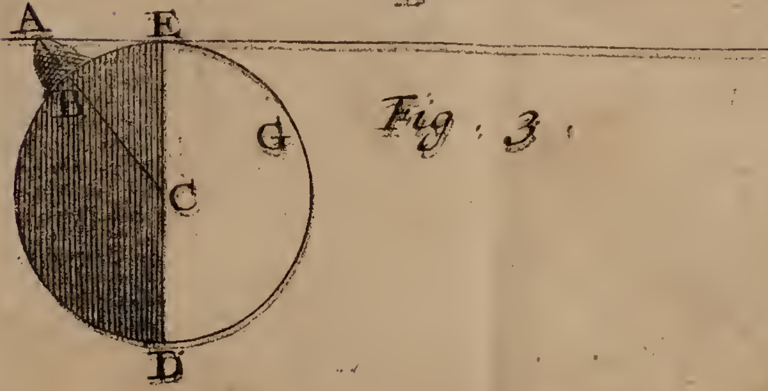


Fig. 3.

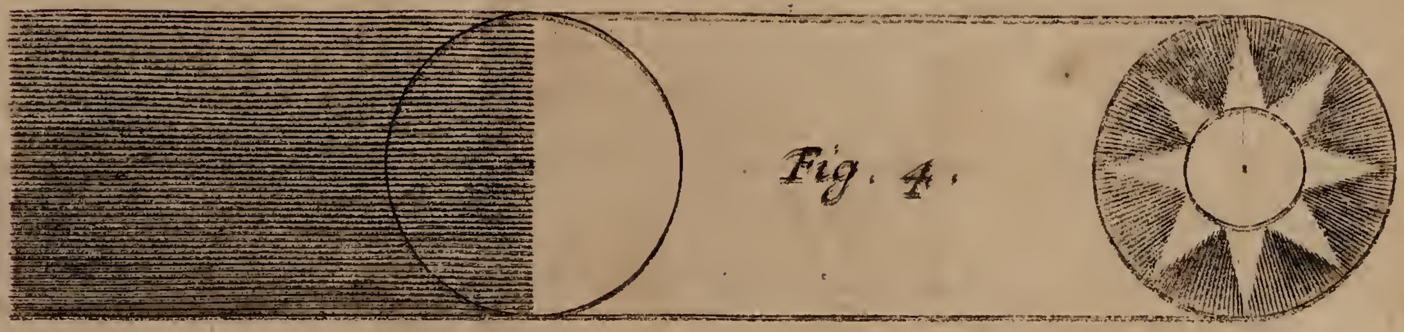


Fig. 4.

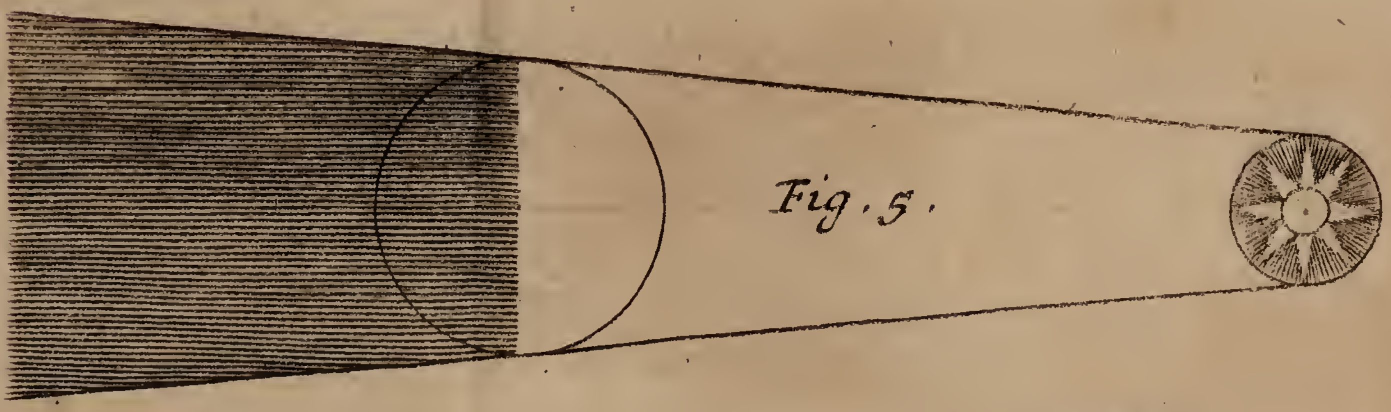


Fig. 5.

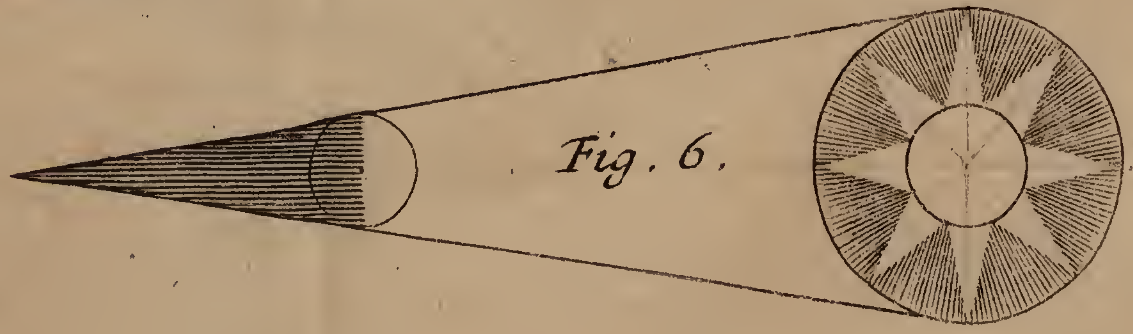


Fig. 6.

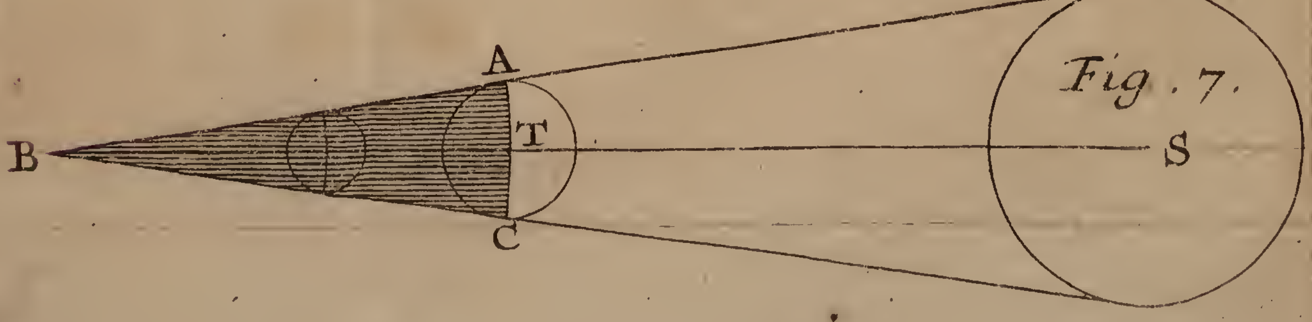


Fig. 7.

in it, when they come to be oppoſite to the *Sun*, and enter within that Space: But this is never obſerved, for then theſe *Planets* would be Eclipſed: And therefore the *Sun* muſt neceſſarily be greater than the *Earth*, whoſe Shadow muſt conſequently be of a Conical Figure, and end in a Point.

The Sun *bigger than the* Earth.

BUT the *Moon*, ſince its Diameter is contained about three times in the Diameter of the Shadow, and the Diameter of the Shadow is leſs than that of the *Earth*, muſt needs be much leſs than our *Earth*.

LET S repreſent the *Sun*, T the *Earth*, and the Cone A B C the Shadow. It is evident there can be no Line drawn from the *Sun*, to any Point of the Space A B C, which does not fall upon the *Earth*: And therefore ſince the *Earth* is an opake Body, it will not ſuffer any Rays to paſs thro', or to illuſtrate the Space A B C. Now if the *Moon* when ſhe is oppoſite to the *Sun* ſhould come into this Space, ſhe muſt then be involved in Darkneſs; and would then ſuffer an Eclipſe in the very time of *Full Moon*.

Plate VI. Fig. 7.

THE *Moon* likewiſe upon the ſame account muſt have a Shadow of a Conical figure oppoſite to the *Sun*; and if this Shadow ſhould fall upon the *Earth*, which can never happen but when the *Moon* is in Conjunction with the *Sun*, the Inhabitants of the *Earth*, on whom the Shadow falls, will be involved in Darkneſs; and the *Sun* will ſeem to them to be in an Eclipſe, ſo long as the Shadow covers them: But becauſe the *Moon* is much leſs than the *Earth*, its Shadow can never cover the whole *Earth*, but only a ſmall Part of it, ſuch as B C: And within that Space only where the Shadow comes, there will be total Darkneſs; and the reſt of the circumjacent places will be illuſtrated with ſome of the *Sun*'s beams, and their Inhabitants will only ſee a part of the *Sun*'s Disk obſcured; which will be greater or leſs, according as they are nearer or further removed

When there can happen an Eclipſe of the Moon.

Plate VII. Fig. 1.

removed from the Shadow, particularly they who live about P, will ſee half the *Sun* Eclipſed: But whoſoever lives between M and N, will ſee at the ſame time all the *Sun*'s Body, and perceive no Eclipſe.

In ſome places of the Earth *an Eclipſe may be total, in others partial, and in others none at all.*

When an Eclipſe of the Sun *happens.*

HENCE it is manifeſt that there can be no Eclipſe of the *Moon* but in *Full Moons*, when ſhe is oppoſite to the *Sun*; as the Shadow always is. Nor can there be any Eclipſe of the *Sun* but in *New Moons*, when ſhe is in Conjunction with the *Sun*; for then only can ſhe caſt her Shadow on the *Earth*. Since therefore in every Month there is one *Full Moon* and one *New Moon*; it may be asked how it comes that the *Sun* and *Moon* do not ſuffer Eclipſes every Month. And indeed if the *Moon* did always move in the Plane of the Ecliptick, ſince the *Axis* of the Shadow is always in the ſame Plane, the *Moon* would then every *Full Moon* paſs thro' the Body of the Shadow, and there would be a total Eclipſe of the *Moon*. So likewiſe in every *New Moon*, if ſhe were not then too far off us, ſhe would caſt her Shadow on the *Earth*, and produce an Eclipſe of the *Sun*, in ſome or other of the Regions of the *Earth*. But the Caſe is otherwiſe, for we have ſhowed that the Plane of the *Moon*'s Orbit, does not coincide with the Plane of the Ecliptick; but that it cuts it in a Line which paſſes thro' the Center of the *Earth*: And therefore the *Moon* is never in the Plane of the Ecliptick, but when it is in this Line, which is the Interſection of the two Planes, that is, when it enters the *Nodes*. And therefore when it happens that the *Moon* at *Full*, ſhall likewiſe be in one of the *Nodes*; then the *Axis* of the Shadow will paſs thro' the Center of the *Moon*, and then ſhe will be in a Total and Central Eclipſe. Let the Circle MN repreſent the tranſverſe Section of the Shadow, at the Diſtance of the *Moon*; and the Line CD a Portion of the Orbit of the *Moon*, which the *Moon* deſcribes in the time of *Full Moon*; which becauſe it is but a ſmall Portion, may be well enough repreſented by

Plate VII. Fig. 2. *Total and central Eclipſes of the* Moon.

by a Right Line: Let the Right Line BGA, be in the Plane of the Ecliptick, and let F be the Poſition of the *Moon*'s Center when ſhe firſt touches the Shadow, E the Poſition of the ſame Center when ſhe firſt leaves it: G the ſame Center of the *Moon* when the *Axis* of the Shadow paſſes thro' it: It is evident, that ſuch an Eclipſe will be Central and Total; and there will always be ſuch Eclipſes when the Center of the *Moon* and *Axis* of the Shadow meet in the *Nodes.* Hence the Duration or time that an Eclipſe can laſt, may be as long as the *Moon* is paſſing thro' an Arch, that is equal to EF, or four Diameters of the *Moon*, that is, about two Degrees, which Space the *Moon* generally moves thro' in the ſpace of four Hours.

BECAUSE of the largeneſs of the Diameter of the Shadow in compariſon of that of the *Moon*, there may be Total Eclipſes which are not central, where the *Node* does not coincide with the *Axis*, and may even lye without the Shadow, as the Figure ſufficiently ſhews. The *Node* may likewiſe be at ſuch a diſtance from the Shadow, that there may be only a part of the *Moon*'s Body that can enter it, and then we ſhall have a Partial Eclipſe of the *Moon*, as is manifeſt by the Figures: and theſe Partial Eclipſes will be greater or leſs, according as the diſtance of the *Node* from the Shadow is leſs or greater. But when it happens that the *Node*, in the time of *Full Moon*, is further removed from the *Axis* of the Shadow than Twelve Degrees, the *Moon* then will have ſo much Latitude, or its diſtance from the Ecliptick, will be ſo great, that it cannot be obſcured by the Shadow.

Plate VII. Fig. 3.

Partial Eclipſes.

Plate VII. Fig. 4, 5.

AS the Shadow of the *Earth* caſt upon the *Moon* produces an Eclipſe of the *Moon*, ſo if the Shadow of the *Moon* ſhould fall upon the *Earth*, it will cauſe an Eclipſe of the *Earth*, at leaſt on that part of the *Earth* on which the

Eclipſes of the Earth.

Shadow falls. For the *Moon* being much leſs than the *Earth*, cannot with its Shadow involve the whole Disk of the *Earth*, but only a very ſmall part of it; and ſo all the Eclipſes of the *Earth* will be Partial and not Total; and ſuch Eclipſes will only produce a darkneſs upon thoſe places where the Shadow falls, and the Inhabitants within this Shadow will only ſee the *Sun* Totally darkned, and therefore they will call them Eclipſes of the *Sun*: but this is improperly attributed to the *Sun*, who all the time retains his Light without the leaſt diminution; and it is only thoſe Inhabitants of the *Earth* that are under the Shadow, that are truly Eclipſed and involved in Darkneſs.

Lines drawn from the Center of the Sun to any Point of the Earth, may be reckoned as Parallel.

THAT we may deſcend more particularly to explain the Phænomena, or Appearances of Eclipſes; it will be requiſite to ſhew the Method of Meaſuring the dimenſions of the Conical Shadows of both *Earth* and *Moon*: For which purpoſe we will firſt lay down the following *Poſtulatum.* If from the Center of the *Sun*, there be drawn Right Lines to every Point of the *Earth*, or to as many as you pleaſe, theſe Lines may all of them be eſteemed as Parallel. For Parallel Lines are ſuch as do not meet till they are produced to an Infinite diſtance; and therefore ſuch Lines as do not meet but at a diſtance immenſly great, in compariſon of the diſtance of the Lines from one another, are nearly, or as we may ſay Phyſically Parallel; that is to ſay, they will have the ſame effect in Nature, and the Phyſical Obſervations that are to be made from them, will be the ſame as if the Lines were abſolutely Parallel. Now the diſtance of the *Earth* from the *Sun* is ſo great, that the Diameter of the *Earth* compared with it, is but as a Point, as is now acknowledged by all Mathematicians; for this Diameter ſeen from the *Sun* does appear under an unperceptible Angle, or which is ſo ſmall that the Eye cannot obſerve it, and the

Plate VIII. Fig. 6.

the *Earth* appears only like a Point: And therefore in compariſon of the great diſtance of the *Sun* it vaniſhes, and conſequently Lines drawn from the Center of the *Sun* to different parts of the *Earth*, will be at leaſt Phyſically Parallel. Moreover it is known in Geometry, that if a Right Line falls upon two other Right Lines, ſo as to make the two internal Angles on the ſame ſide equal to two Right Angles, that theſe two Lines on which it falls are Parallel, by 29 *Prop.* Book firſt of *Euclide.* Let therefore the Line A B be the Diameter or Semidiameter of the *Earth*, and C the Center of the *Sun*: drawing A C and B C, the Angles A, B and C of the Triangle A B C are equal to two right Angles: Now the Angle C at the *Sun* vaniſhes, and is next to nothing, for the *Earth* ſeen from the *Sun* looks like a Point; and therefore the Angles at A and B muſt make by themſelves two Right Angles very nearly, and therefore the Right Lines A C, B C, are nearly Parallel. It is upon the ſame account that if there be taken two Threads with Plummets to make them hang perpendicularly, the Directions of thoſe Threads are by all Artificers eſteemed as Parallel, tho' their directions will meet at the Center of the *Earth*, to which all heavy Bodies have a *Tendency*, or *Propenſion.*

WHAT we have ſaid in this caſe concerning the *Earth*, is alſo true of the *Moon*, for its Diameter has a much leſs proportion to the diſtance of the *Sun*, than that of the *Earth* has to it. And not only Lines drawn from the *Sun* to any Points of the *Earth* and *Moon*, are to be reputed Parallel; but if there be two Lines drawn, one from the Center of the *Sun* to the *Earth*, the other from thence to the *Moon*, theſe may be likewiſe taken as Parallels, for they will not ſenſibly differ from a Paralleliſm, eſpecially in the time of Eclipſes: the difference of theſe Lines from real Parallels

Lecture XI.

is ſo ſmall, that it will make no ſenſible error in the Calculation of Eclipſes.

WE likewiſe premiſe the following *Lemma*, which is eaſily demonſtrated.

Plate VII. Fig. 7. *A* Lemma.

IF two Right Lines AE BF *touch a Circle, and there be drawn from the Points of Contact to the Center the Lines* AD BD; *the Angle at the Center contain'd under theſe Lines, will be equal to the Angle that the Tangents make with one another.* For in the Four-ſided Figure GADB, all the Angles make four Rights: But the Angles A and B make two Rights, by the 18 *Prop.* Book third of *Euclide*: Wherefore the Angles A G B and D, are equal to two Rights. But by the 13 *Prop.* Book firſt of *Euclid*, the Angles A G B and E G B, are equal to two Right Angles, and therefore the Angles D and E G B are equal, ſince the Angle A G B makes two Right Angles with either of them.

The Dimenſion of the Angle of the Conical Shadow. Plate VII. Fig. 8.

LET the Circle A B K repreſent the Globe of the *Earth*, A M the Line which joins the Centers of the *Sun* and *Earth*; to which let the Diameter C B be perpendicular: if from B there be drawn to the Center of the *Sun* the Line E F, this Line will be Parallel to the Line C M, as has been ſhown: Make the Angle B C D equal to the Apparent Semidiameter of the *Sun*, that is, equal to the Angle under which the Semidiameter of the *Sun* is ſeen from the *Earth*, and then thro' D draw the Tangent D G. By the *Lemma* above demonſtrated, the Angle G E F will be equal to the Angle B C D, or to the Apparent Semidiameter of the *Sun*; and therefore ſince the Line B F produced goes to the Center of the *Sun*, the Line G E D muſt touch its Circumference, and it will alſo touch the *Earth*, and being produced, will meet with the *Axis* of the Shadow C H in H, ſo that the Angle D H C, will be half the Angle of the Conical Shadow. Now becauſe E F is Parallel to M H, the Angles D H C and G E F are equal, by the 29

Prop. Book firſt of *Euclid.* But GEF is equal, as has been ſhewed, to the Apparent Semidiameter of the *Sun*; wherefore the whole Conical Angle KHD, is equal to the Apparent Diameter of the *Sun.*

THE ſame thing is to be demonſtrated of the *Moon*, and Univerſally, the *Sun*'s Apparent Diameter remaining the ſame in all Spheres, which are not bigger than the *Earth*, the Angles of the Conical Figures which include the Shadows are all equal, and all their Shadows will be Semilar Figures. This may likewiſe be demonſtrated in this manner.

Theſe Angles in all Conical Shadows are equal.

Plate VII Fig. 5.

LET AGF be the *Sun*, DHE the *Earth*, SC a Line joining the Centers of the *Sun* and *Earth*, AD a Right Line which touches both Bodies; and let the Lines AD SC produced meet in M, the Angle AMS will be half the Angle of the Shadowed Cone. Now in the Triangle SDM, the outward Angle ADS is equal to both the inward and oppoſite Angles, by *Prop.* 32 Book firſt of *Euclid*; that is, the Angles DMS and DSM are equal to the Angle ADS: but the Angle DSM is nothing, or next to nothing, being the Angle under which the Semidiameter of the *Earth* appears as ſeen from the *Sun*, and the Angle ADS is the Apparent Semidiameter of the *Sun*; therefore the Angle DMS or the Semiangle of the Cone, is equal to the Apparent Semidiameter of the *Sun.*

Lecture XII.

LECTURE XII.

Of the Penumbra *and its Cone, the Height of the Shadow, and the Apparent Diameters of the Shadows.*

BESIDES the Shadow which is deprived of all the *Sun*'s Light, there is a certain Space which is but a Partial Shadow and is called a *Penumbra*; for tho' all the *Sun*'s Body does not illuminate it, there are for all that Rays coming from ſome part of the *Sun*, which doe enter it, and render it lucid, the reſt of the *Sun*'s Beams being intercepted by the Opake Body of the *Earth*: and the parts of this *Penumbra* will have different Degrees of Illumination, according as they are nearer or further removed from the Shadow. The Space of the *Penumbra* is to be determined in this manner.

Plate VIII. Fig. 1. LET the Circle A E F G repreſent the *Sun*, HED any Opake Sphere, for Example the *Moon*, it being her *Penumbra* that we are at preſent concerned with; S C the Line which joins the Centers of both Spheres. Draw the Line F D O, touching the Left ſide of the *Sun* and the Right ſide of the *Moon*, and the Line A H P, which touches the Right ſide of the *Sun* and the Left of the *Moon*: let theſe two Lines cut the Line S C in I. The Point I remaining immoveable, either of the Right Lines I D O, or I H P being extended indefinitely, let them be turned round the *Axis* I M, with a Conical Motion, ſo that they may always touch the

Plate VII

front. p. 118.

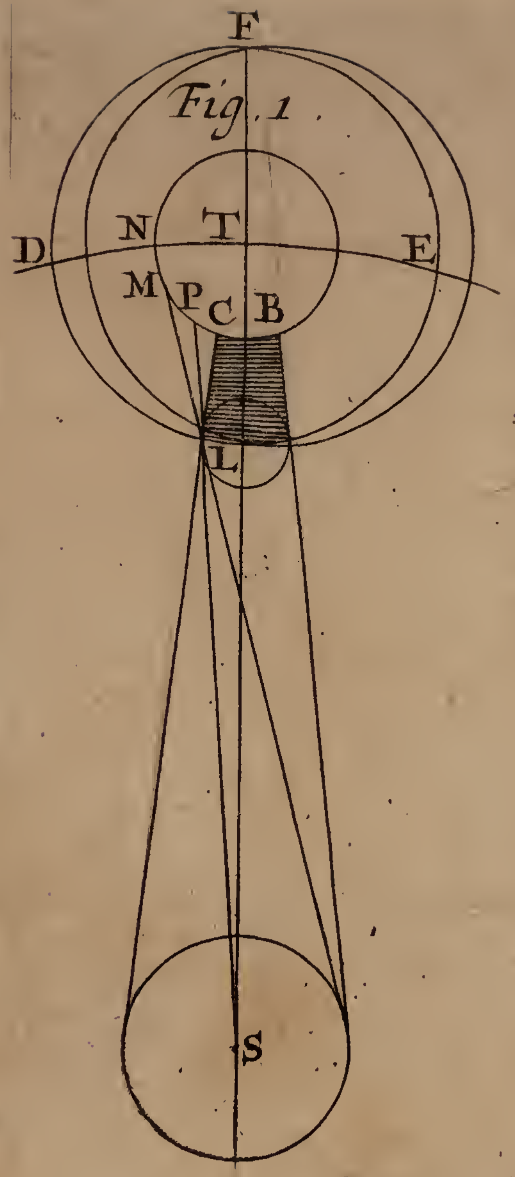


Fig. 1.

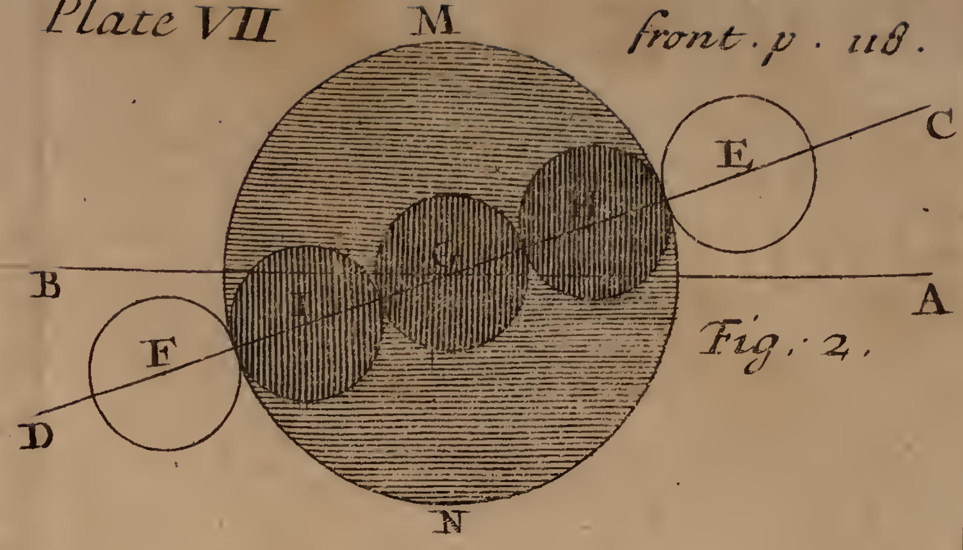


Fig. 2.

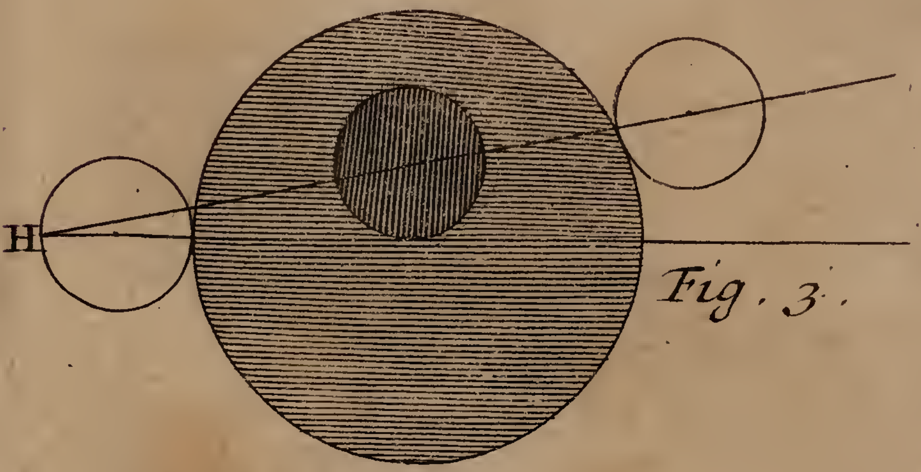


Fig. 3.

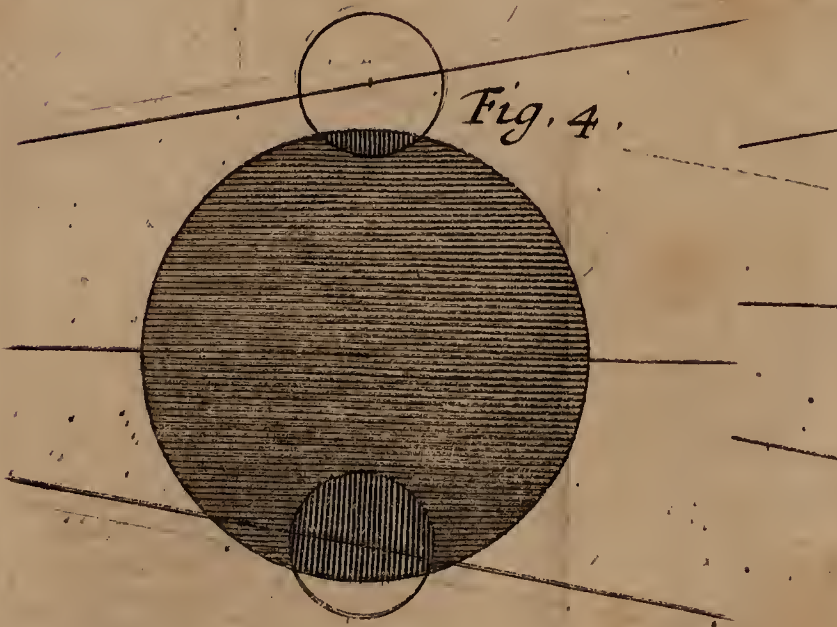


Fig. 4.

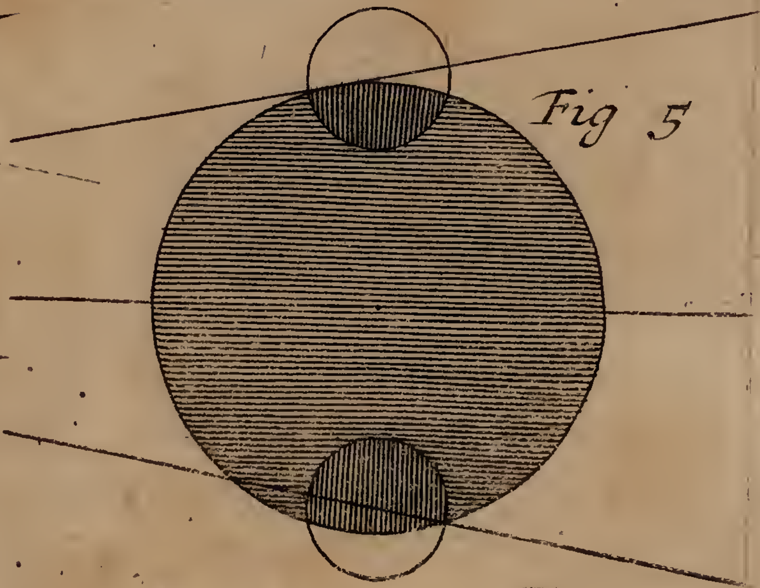


Fig 5

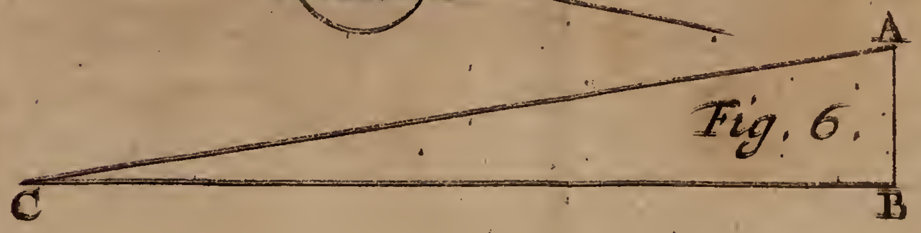


Fig. 6.

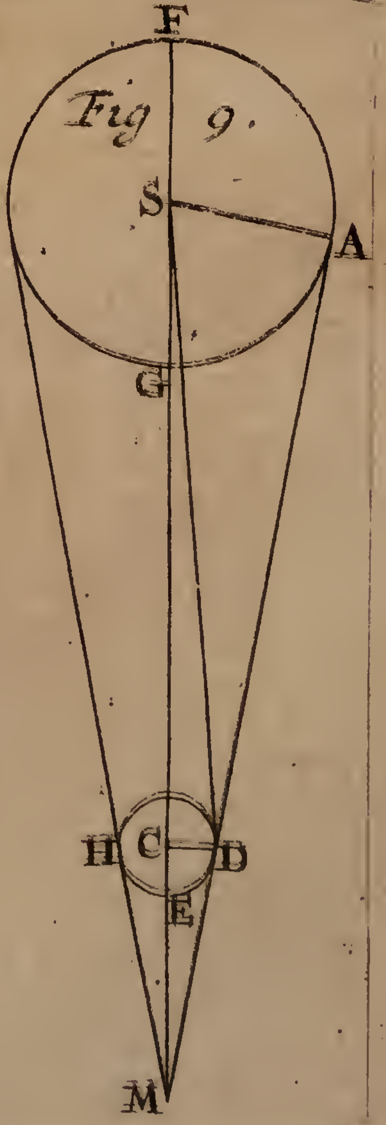


Fig 9.

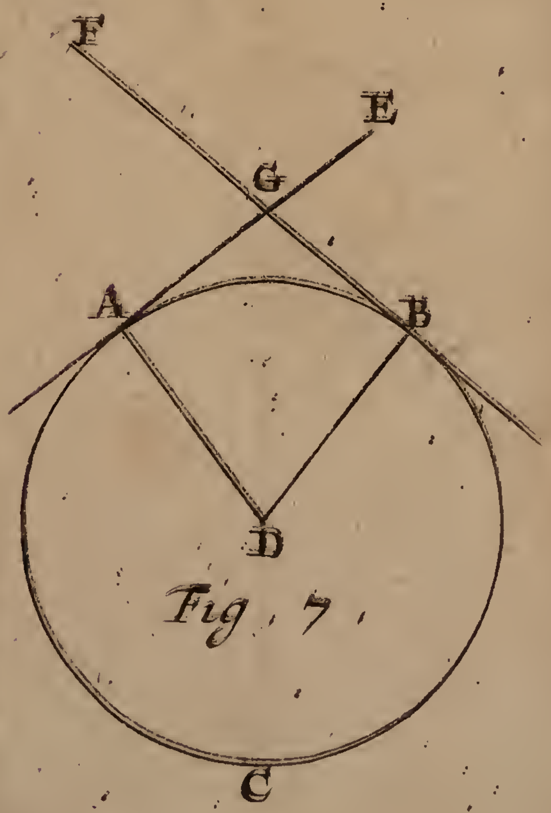


Fig. 7.

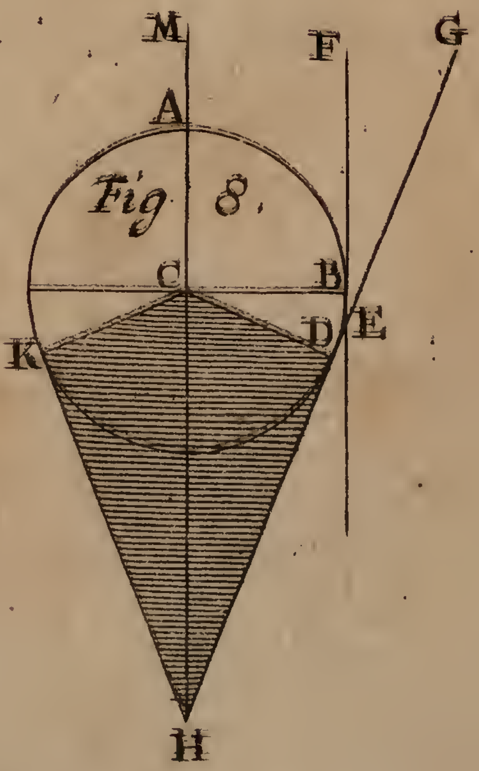


Fig 8.

Globe of the *Moon*; there will by that means be generated an indefinite Conical Surface, including both the Shadow and the Circumambient Space ODM PHM; into which Space ſome Rays of the *Sun* are hindred from entering by the Opake Body of the *Moon*: And this is the Space which we call the *Penumbra*, which is darker in X or Y, which are nearer the Borders of the Shadow, than in V and N, which are nearer the Conical Surface. For the places X and Y are illuſtrated with a ſmaller Portion of the *Sun*'s Disk, than the other places further diſtant from the *Axis* of the Cone. Now if the *Earth* come within this Space, a certain Portion of its Surface at S may be included in the Total Darkneſs, and the Inhabitants of that Region will ſee a Total Eclipſe of the *Sun*; but thoſe who live without this Shadow, but are ſtill within the *Penumbral* Space, as about Q and X, will have no Total Darkneſs, ſome part of the *Sun*'s Disk being ſtill viſible, while the reſt is hid by the *Moon*. For let us draw from Q the Line QD, touching the Globe of the *Moon*, which being produced to the *Sun*, the Point Q being immoveable, if the Line QD indefinitely extended be moved by a Conical Motion round the *Moon*, the Conical Surface it deſcribes, will cut off a Portion of the *Sun*'s Disk, which is covered by the *Moon*.

Plate VIII. Fig. 2. *The dimenſions of the Conical* Penumbra.

WE find the Dimenſions of the Cone of the *Penumbra* in this manner. Let the Circle HDL repreſent the Opake Sphere of the *Moon*, SC the Line joining its Center with the Center of the *Sun*; and let CB the Semidiameter of the *Moon* be Perpendicular to CS, and BF Parallel to it touching the *Moon* in B. Make the Angle BCD equal to the Apparent Semidiameter of the *Sun*, and thro' D draw DG a Tangent to the *Moon*. And by the *Lemma* premiſed, the Angle FEG will be equal to the Angle BCD, or to the Apparent Semidiameter of the *Sun*;

and

Lecture XII.

and therefore ſince the Line E F goes to the Center of the *Sun*, the Line E D G muſt touch the Inferior Limb of the *Sun*: but it alſo touches the *Moon*; and therefore the Point of this Line being immoveable, if it be carried by a Conical Motion round the *Moon*, it will generate the Surface which includes the *Penumbra.* And becauſe of the Parallels E F, C S, the alternate Angles F E I and E I C will be equal; but the Angle E I C is the Semiangle of the Cone, and F E I is the Apparent Semidiameter of the *Sun*; and therefore half the Angle of the *Penumbral* Cone, is always equal to the Apparent Semidiameter of the *Sun.* The Cone therefore of the Total Shadow, and that part of the *Pennmbral* Cone which lies between the *Sun* and the *Moon*, are equal and ſimilar Figures; for they have their Vertical Angles and Baſes equal.

Plate VIII. Fig. 3.

THE Height of the Shadow of the *Earth* is thus determined. Let C T be the Semidiameter of the *Earth*, T M the height of the Cone or Shadow: If T M be the Radius, C T will be the Sine of the Angle T M C, which is half the Angle of the Cone. And this Angle is equal to the Apparent Semidiameter of the *Sun* as has been ſhewed, and in the mean diſtance of the *Sun*, is about 16 Minutes. Let therefore the Sine of 16 Minutes be to the Radius, as the Semidiameter of the *Earth* to a fourth, and we ſhall find T M equal to 214,8 Semidiameters of the *Earth*: But when the *Sun* is at his greateſt diſtance, half the Angle of the Cone is 15 Minutes and 50 Seconds, and the Height of the Shadow becomes 217 Semidiameters of the *Earth*: and ſince the Diameter of the *Earth* is to the Diameter of the *Moon*, as 100 is to 28; the Altitude of the *Earth*'s Shadow, will be to the Altitude of the *Moon*'s in the ſame Proportion, for the Conical Shadows are ſimilar Figures; and therefore the Height of the *Moon*'s Shadow will be 59,36 Semi-

The height of the Earth's *Shadow.*

The height of the Moon's *Shadow.*

Semidiameters of the *Earth*: Hence, if the diſtance of the *Moon* from the *Earth* be greater than her mean diſtance, which is about 60 Semidiameters of the *Earth*, the Shadow of the *Moon* cannot reach the *Earth*, in which caſe there may be a Central Eclipſe of the *Sun* but not a Total one: But round the *Moon* there will appear part of the *Sun*'s Body, in the form of a Luminous Circle, which like a bright ſhining Ring of Gold, will embrace the Body of the *Moon*. It alſo follows, that if in the time of the Eclipſe, the Anomaly of the *Moon* be leſs than three Signs, or bigger than nine Signs, there can no where be a Total Eclipſe of the *Sun*, for in all theſe Degrees of Anomaly, the diſtance of the *Moon* is greater than her mean diſtance.

The Portion of the Earth's *Surface that may be involved in the Shadow.*

TO find how much of the *Earth*'s Surface can be involved in the *Moon*'s Shadow in the time of an Eclipſe, when it directly falls upon it: Let us ſuppoſe the diſtance of the *Sun* to be the greateſt that can be, in which caſe the height of the Conical Shadow of the *Moon* is about 60 Semidiameters of the *Earth*: Let us likewiſe ſuppoſe the diſtance of the *Moon* from us to be the leaſt that can be, that the *Earth* may receive the moſt of the Shadow. This leaſt diſtance of the *Moon* from the *Earth* is about 56 Semidiameters of the *Earth*: Now let L represent the *Moon*, and T the Center of the *Earth*, L T the diſtance of the *Moon* from the *Earth*, which is equal to 56 Semidiameters; and ſince I M is 60, T M muſt be four Semidiameters, and T B will be to T M as 1 to 4. But as T B is to T M, ſo is the Sine of the Angle T M B, which is 15′ 50″, to the Sine of the Angle T B M; by which means we find the Angle T B M to be 63 Minutes and 10 Seconds. But the Angle A T B is equal to both T M B and T B M, by 32 *Prop.* Book 1ſt. of *Euclid*, and therefore the Angle A T B is 79 Minutes, and ſuch is the Arch A B; the double

Plate VIII. Fig. 4.

of which is the Arch B C equal to 158 Minutes, or to 180 Engliſh Miles. We have here ſuppoſed the *Axis* of the ſhade to paſs thro' the Center of the *Earth*; which it does when the Centers of the *Sun*, *Earth* and *Moon* are in the ſame Right Line preciſely: but when the three Centers do not lye in the ſame Right Line, the Conical Shade is cut obliquely, and the Figure of it upon the *Earth* is Oval, whoſe Diameter is eaſily to be determined by the diſtance of the *Moon* from the *Sun* ſeen from the Center of the *Earth*.

How much of the Surface may be included in the Penumbra. Plate VIII. Fig. 5.

IF we inquire how much of the Surface of the *Earth* can be involved in the *Penumbra*; it may be found by this means: Let us ſuppoſe the Apparent Diameter of the *Sun* to be the greateſt, which is when the *Earth* is in her *Perihelion*, and is about 16′ 23″. Let A B D be the *Earth*, L the *Moon*, and A M B be half the Angle of the Cone, which is likewiſe 16′ 23″: By which we ſhall find the height of it L M, equal to 58 and a half Semidiameters of the *Earth*: Let the *Moon* be in her *Apogeon*, and therefore at her greateſt diſtance from the *Earth*, which is 64 Semidiameters of the *Earth*; and T M is equal to both T L and L M, that is to $122\frac{1}{2}$ Semidiameters: but by a Trigonometrical Theorem, T B is to T M, as the Sine of the Angle T M B is to the Sine of the Angle M B N or M B T. But T B is to T M as 1 is to $122\frac{1}{2}$, and the Angle T M B is 16 Minutes 23 ſeconds, and therefore we ſhall find out the Angle M B N to be 35 Degrees and 42 Minutes, which Angle is equal to both the Angles T M B and M T B. If therefore from the Angle M B N 35 Degrees 42 Minutes, we Subſtract the Angle T M B, there will remain the Angle M T B 35 Degrees 25 Minutes, which is the meaſure of the Arch A B; whoſe double 70 Degrees and 50 Minutes, is equal to the Arch C A B which makes about 4900 Engliſh Miles.

IF the Conical Shadow of the *Earth* at the diſtance of the *Moon*, be cut with a Plane

Perpendicular to its *Axis*, the Section will be a Circle, which is called the Shadow, whoſe Apparent Diameter ſeen from the Center of the *Earth*, is thus determined. Let T be the Center of the *Earth*, C M T half the Angle of the Cone, F L H the Section whoſe Diameter is F H. Having the Angle of the Cone, we by that means can find its Altitude T M; but we have alſo T L, the diſtance of the *Moon* from the *Earth*, and therefore we can find M L; but we have alſo the Angle F M L, therefore we can find out F G half the Diameter of the Shadow at the diſtance of the *Moon:* and therefore in the rectangled Triangle F T G, having the two ſides F G and T G, we can find by Trigonometry the Angle F T G, the apparent ſemidiameter of the Shadow ſeen from the Center of the *Earth.* It may likewiſe be thus found; having F T the diſtance of the *Moon* from the *Earth*, and C T the Semidiameter of the *Earth*; in the Triangle C F T, we may find out the Angle C F T, which is equal to the two Angles F M T and F T M: if therefore we ſubſtract the Angle F M T, which is half the Angle of the Cone, from the Angle C F T, we ſhall find the Angle FTM or FTL: The Angle CFT is the Apparent Semidiameter of the *Earth* ſeen from the *Moon*, and is called the *Horizontal Parallax* of the *Moon*, the reaſon of which we ſhall ſhew when we come to treat about *Parallaxes.* Theſe Apparent Semidiameters of the *Earth*, or *Horizontal Parallaxes* of the *Moon*, conſtantly vary as the diſtance of the *Moon* does, and they are found ready Calculated in all *Aſtronomical* Tables.

The Apparent Diameter of the Shadow of the Earth *at the diſtance of the* Moon *determined.* Plate VIII. Fig. 3.

Another way of finding the ſame.

The Horizontal Parallax *of the* Moon.

LET ☊ M be a Portion of a Line in the Plane of the Ecliptick, ☊ L a Portion of the Lunar Orbit, which the *Moon* moves through, about the time of *Full Moon*, which becauſe it is ſmall, may be repreſented by a Right Line. Let the Circle F M O repreſent the Shadow of the *Earth* at the diſtance of the *Moon*, and its Center G; G L is the Latitude of the *Moon* in the

Plate VIII. Fig. 6.

Plate IX. Fig. 1, 2.

The Limits of Eclipſes.

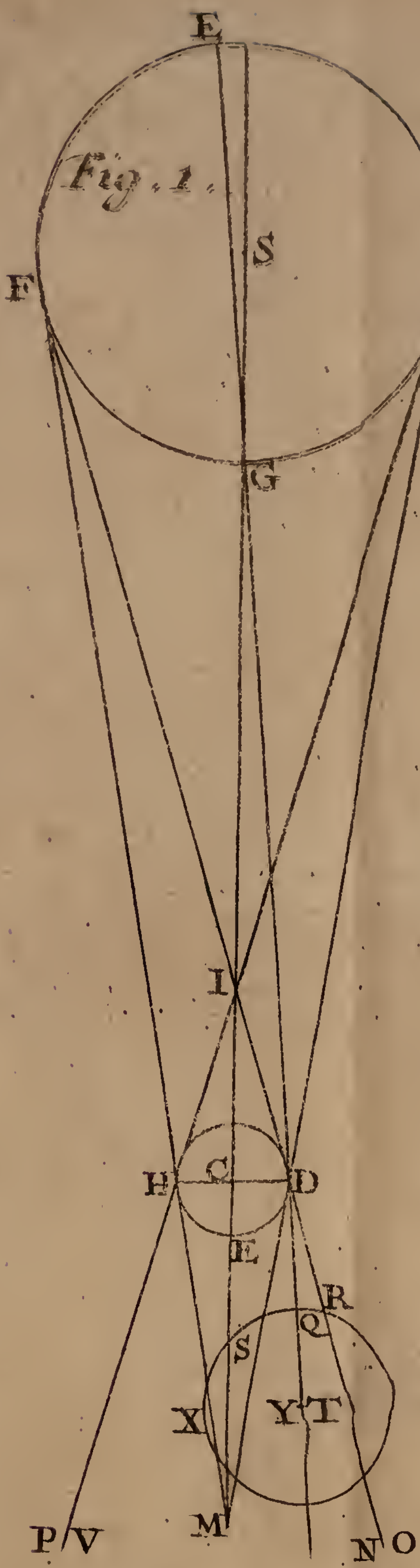
Plate IX. Fig. 3.

The Limits determined.

time of *Full Moon*, which is almoſt equal to the ſhorteſt diſtance of the *Moon* from the Plane of the Ecliptick. It is manifeſt that if G L the Latitude of the *Moon*, be greater than the ſum of the Semidiameters of the *Moon* and Shadow; then the *Moon* will no part of it enter into the Shadow. But if the Latitude of the *Moon* be juſt equal to theſe two Semidiameters, than the Limb of the *Moon* will juſt touch the Shadow, but not enter it: But if the Latitude of the *Moon* be leſs than this ſum, but greater than their difference, there will be a Partial Eclipſe; and if the Latitude of the *Moon* be leſs than the difference of the Semidiameters of the *Moon* and Shadow, the Eclipſe will be Total: And by this means we can find out the Ecliptick Terms or *Limits*, which are ſuch that if the diſtance of the *Moon* from the *Node* be leſs than they are, in the time of *Full Moon* there will be an Eclipſe: If greater there can be no Eclipſe. Let ☊ S repreſent a Portion of a Line in the Plane of the Ecliptick Parallel to the *Earth*'s Orbit, ☊ L a Portion of the *Moon*'s Orbit, S L the Latitude of the *Moon* when at *Full*; and let us ſuppoſe this Latitude to be ſuch, that the Margin of the *Moon* may juſt touch the Shadow, and let the *Node* be at ☊. The Angle L ☊ S is the inclination of the Orbit of the *Moon* to the Plane of the Ecliptick, which is five Degrees; and L S the Latitude of the *Moon*, when its Limb touches the Shadow, equal to 66 Minutes; and therefore in the rectangular Triangle ☊ L S, having L S and the Angle L ☊ S, we can find ☊ S, the diſtance of the *Node* from the Point of the Ecliptick oppoſite to the *Sun*, which is 754 Minutes or 12 Degrees 34 Min. And if in the time of *Full Moon*, the *Moon*'s place in the Ecliptick be further diſtant from the *Node* than 12 Degrees 34 Minutes, there can then be no Eclipſe of the *Moon*.

LET L be the Center of the *Moon*, whoſe Conical Shadow is D M E. Imagine this Sha-

Plate VIII *front. p. 124.*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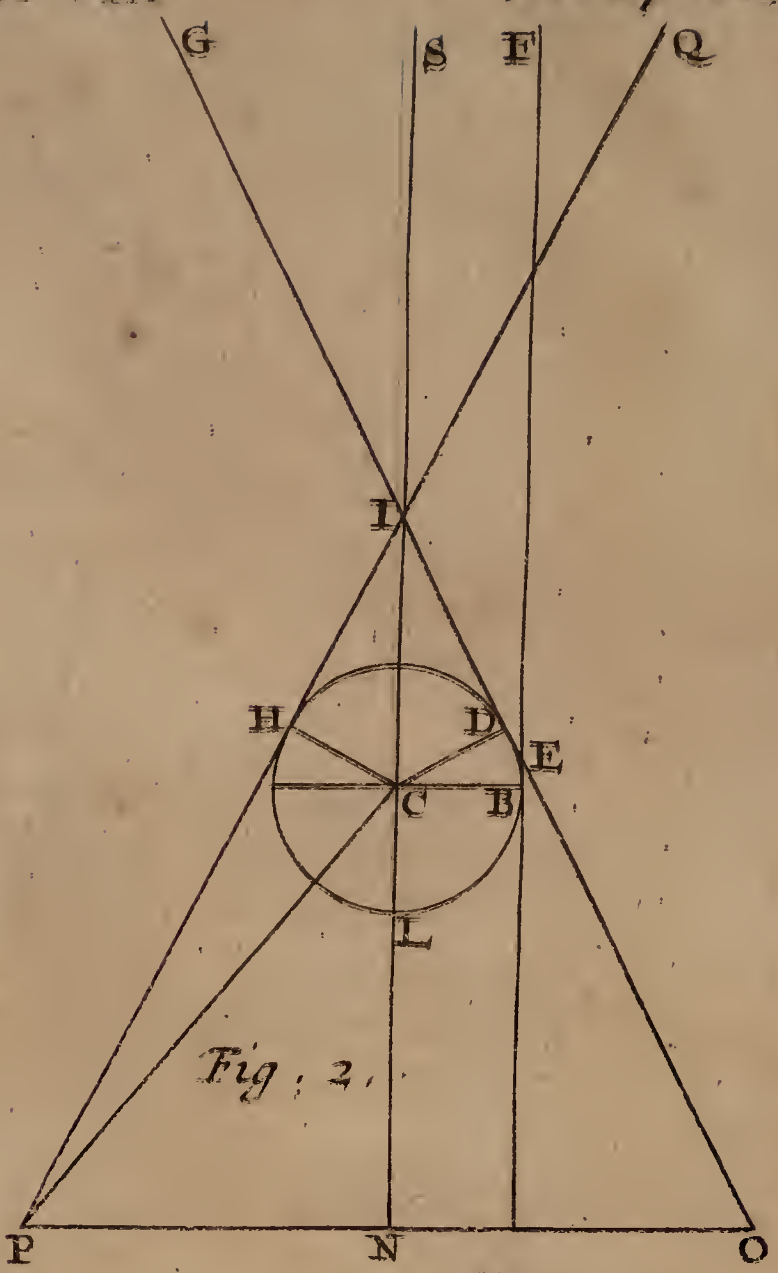
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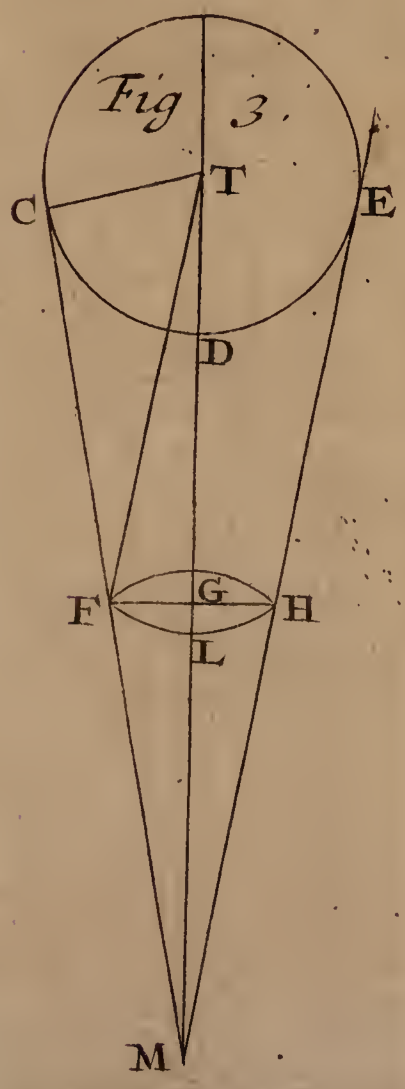
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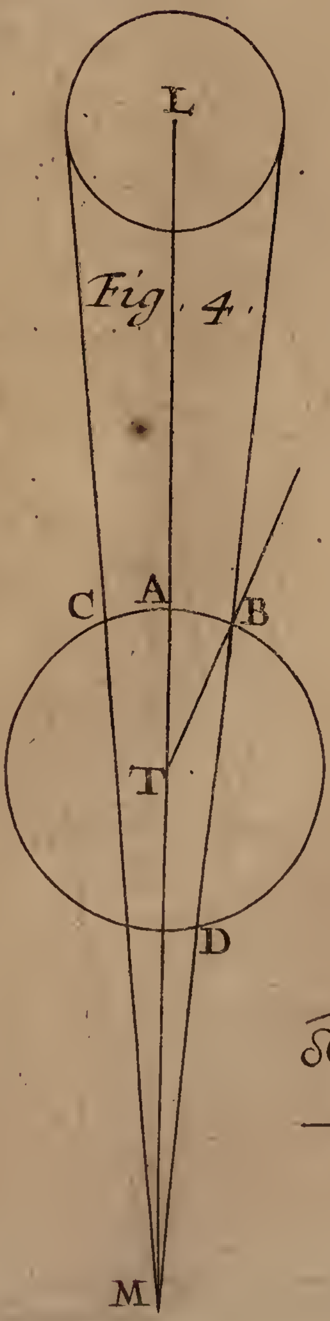


Fig. 4.

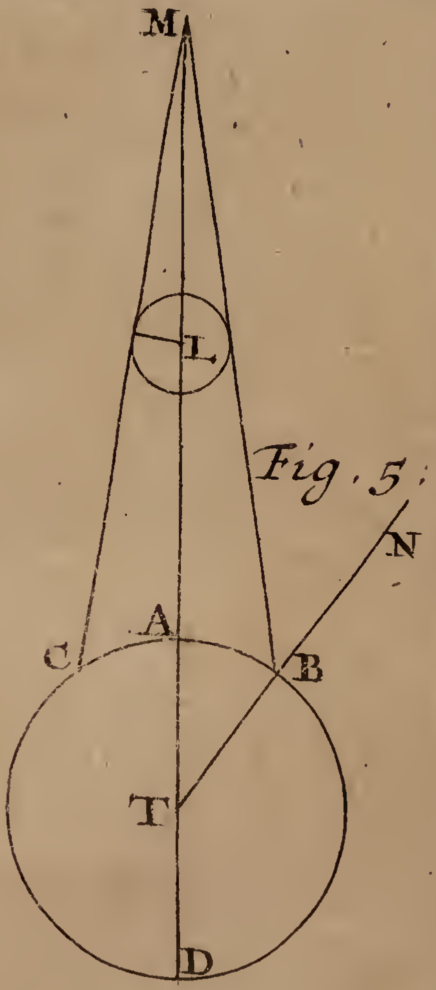


Fig. 5.

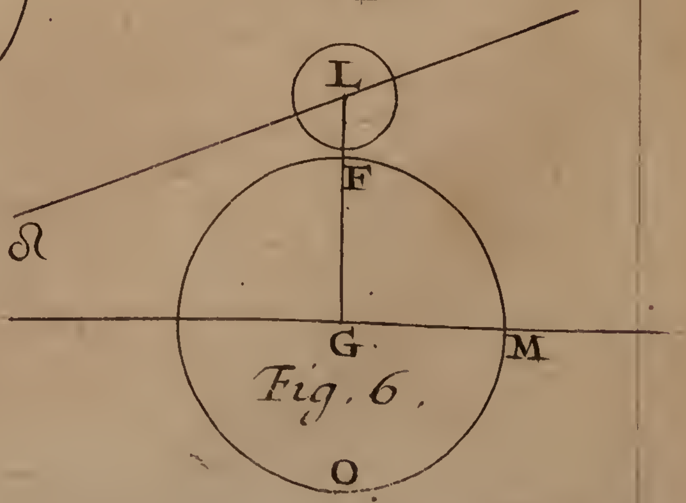


Fig. 6.

dow cut at the diſtance of the *Earth* with a Plane perpendicular to its *Axis*; the Section will be a Circle, whoſe Semidiameter T P is called the Semidiameter of the *Moon*'s Shade: Now the Angle under which this Semidiameter appears ſeen out of the *Moon*, is equal to the difference of the Semidiameters of the *Sun* and *Moon* ſeen from the *Earth*: For the Angle L P D is the Apparent Semidiameter of the *Moon* ſeen from the *Earth*, which is equal to the two internal Angles P M L and P L M; and therefore if we ſubſtract from the Angle L P D, which is the Apparent Semidiameter of the *Moon*, the Angle P M L which is equal to the Apparent Semidiameter of the *Sun*, there will remain the Angle P L T, the Apparent Semidiameter of the Shadow ſeen from the *Moon*.

Plate IX. Fig. 4.

The Diameter of the Moon's *ſhadow at the* Earth *when ſeen from the* Moon.

AGAIN, let L be the Center of the *Moon*, A M B the *Penumbral* Cone of the *Moon* extended as far as the *Earth*, and its *Axis* M T; if this Cone at the diſtance of the *Earth* be cut by a Plane tranſverſely, the Section will be a Circle whoſe Semidiameter is A T, and is called the *Semidiameter of the Penumbra.* And the Angle under which it appears from the *Moon* is the Angle T L A, which is the external Angle of the Triangle L M A, and is equal to both the inward Angles L A M and L M A. But the Angle L M A is half the Angle of the Cone, which is the ſame with the apparent Semidiameter of the *Sun*, and M A L or C A L is equal to the apparent Semidiameter of the *Moon* ſeen from the *Earth*; and therefore the Apparent Semidiameter of the *Penumbra* ſeen from the *Moon*, is equal to the ſum of the Semidiameters of both *Sun* and *Moon*.

Plate IX. Fig. 5.

The Apparent Diameter of the Penumbra.

IF the *Sun* had no Apparent Motion ariſing from the real Motion of the *Earth*, the way of the *Moon* from the *Sun* would be the ſame with her real way in her Orbit. But becauſe while the *Moon* is proceeding in her Orbit, the *Sun* alſo ſeems to move in the Ecliptick, the

The way of the Moon *from the* Sun.

Plate IX. Fig. 6.

way the *Moon* moves towards or from the *Sun*, will be different from that which ſhe has in her Orbit, and its inclination to the Ecliptick will be greater than the inclination of the Orbit to it. Let ☊ A be a Portion of the *Moon*'s Orbit produced to the Ecliptick: And ſuppoſe the *Sun* and *Moon* in Conjunction in the *Node*: Now then while the *Moon* in her Orbit deſcribes the Space ☊ L, the *Sun* by his Apparent Motion will deſcribe the Space ☊ S in the Ecliptick, and S L will be the way of the *Moon* from the *Sun*. Now if two Bodies be both moved the ſame way, but one faſter than the other, their relative Motion whereby the one recedes from the other, is the ſame as if the ſloweſt Body ſtood ſtill and the other moved on with the difference of Velocities, as we have demonſtrated in our Phyſical Lectures. Thro' the place of the *Moon* L, draw B L Parallel to the Ecliptick, to which let ☊ B be Perpendicular. Now while the *Moon* in her Orbit deſcribes the Space ☊ L, its Motion according to the Ecliptick is equal to the Space B L; take L *l* equal to ☊ S, and draw ☊ *l*, it will be Parallel to S L; and the Motion of the *Moon* from the *Sun* will be the ſame as if the *Sun* had remained in the *Node*, and the *Moon*, according to the Ecliptick, had been carried with the Velocity B *l*, which is the difference of the Velocities of the *Sun* and *Moon*, according to the Ecliptick. Becauſe the Angles B L ☊ and B *l* ☊ are but ſmall, the Angle B L ☊ will be to the Angle B *l* ☊, as B*l* is to B L, that is, as the difference of the Motions of the *Sun* and *Moon* according to the Ecliptick, is to the Motion of the *Moon* in the Ecliptick, ſo will the Angle which the Orbit of the *Moon* makes with the Ecliptick be to the Angle B *l* ☊, which is equal to the Angle LSE, or the Inclination of the way of the *Moon* from the *Sun* to the Ecliptick: And by this means we can find out the Angle which a Circle of Latitude drawn thro' any Point of the Eclip-

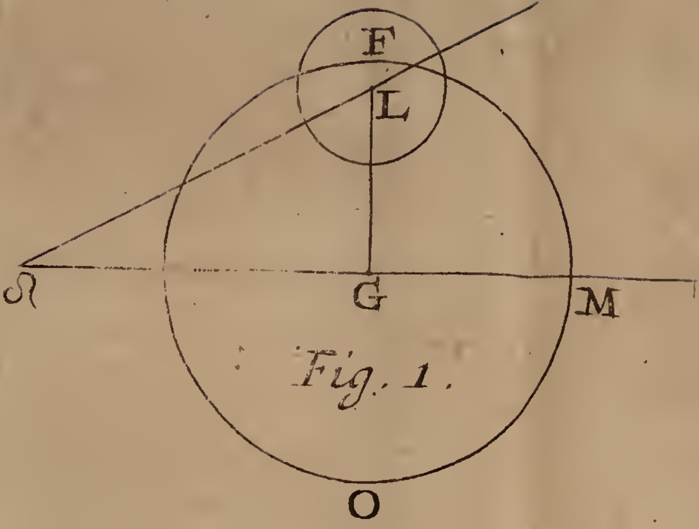


Fig. 1.

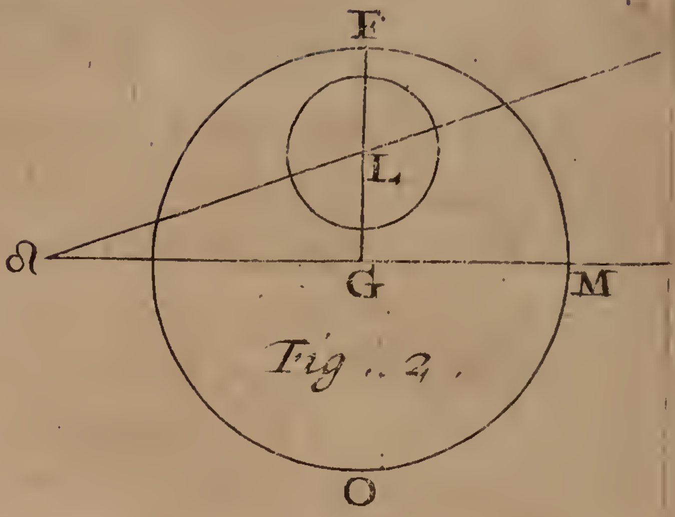


Fig. 2.

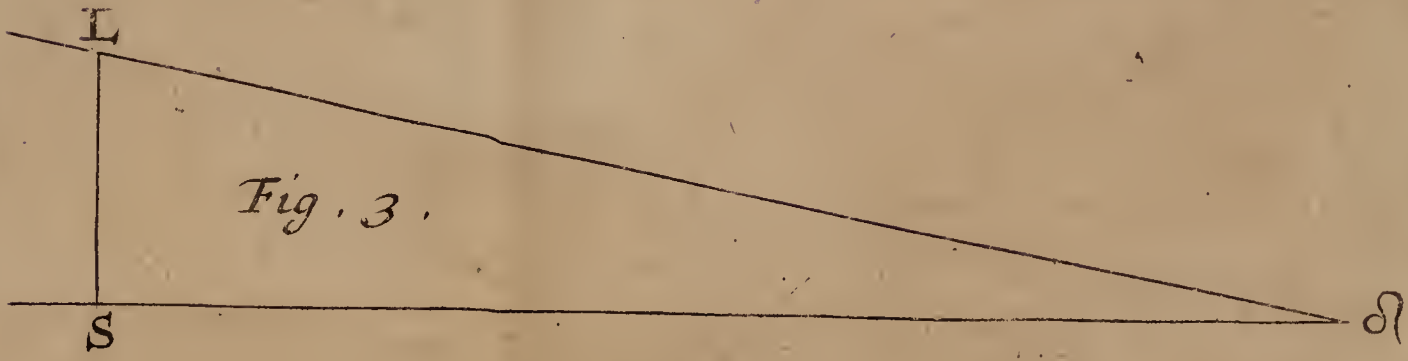


Fig. 3.

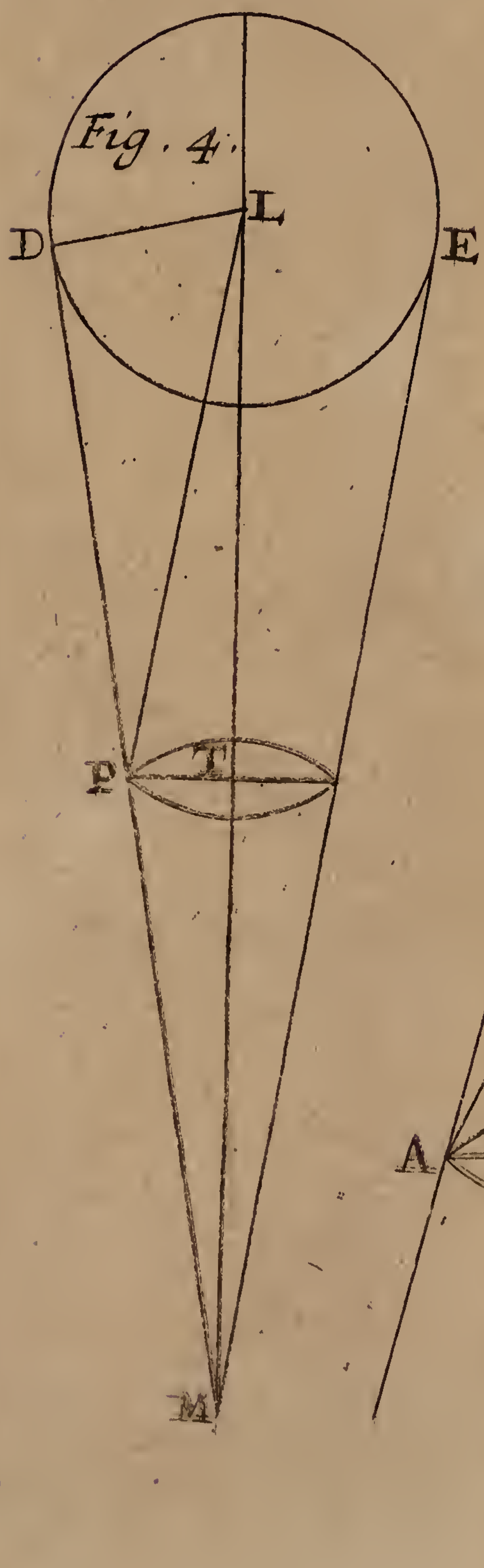


Fig. 4.

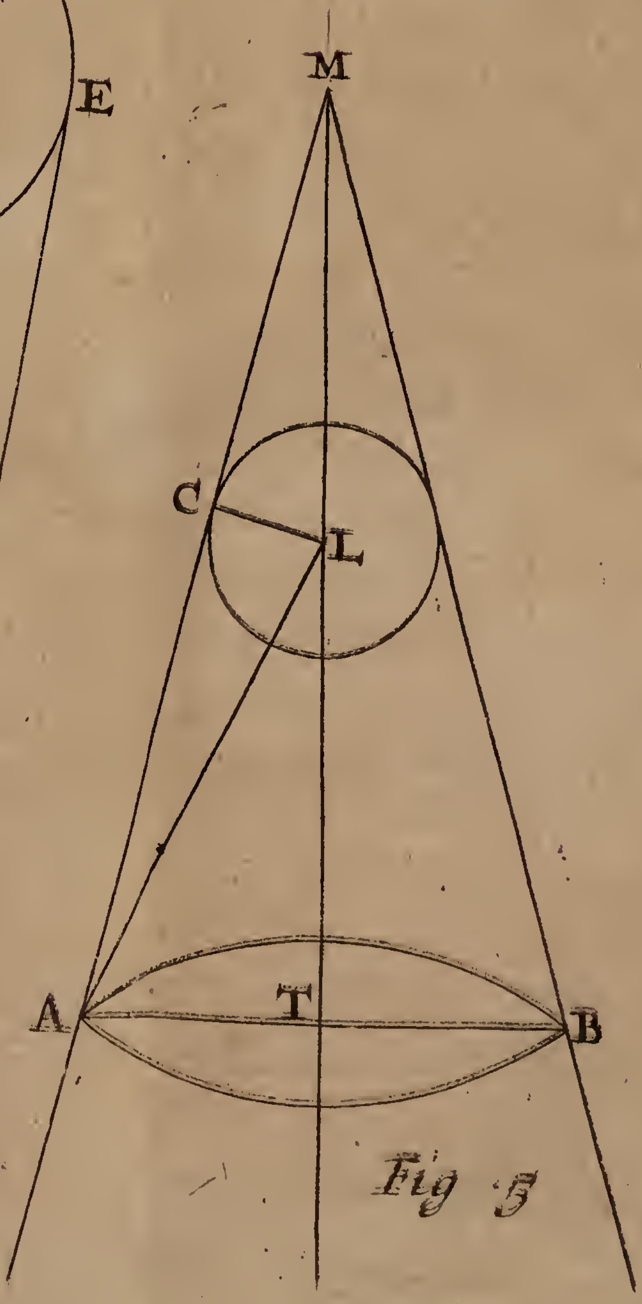


Fig. 5.

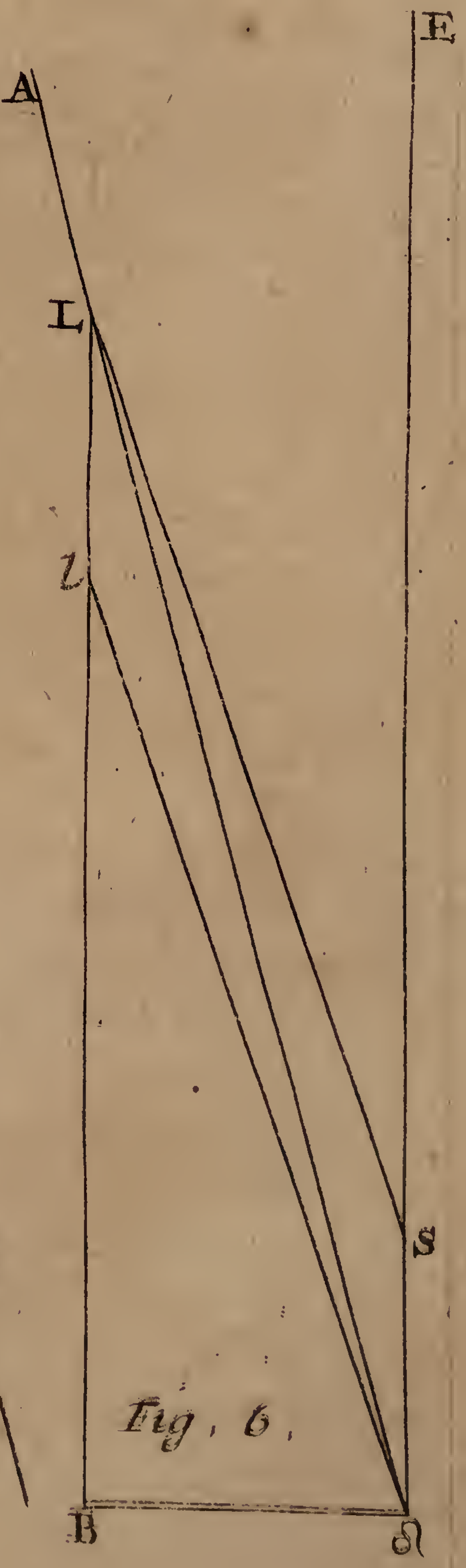


Fig. 6.

tick makes with the way of the *Moon* from the *Sun*. For in the rectangular Spherical Triangle which the Ecliptick, the Circle of Latitude and the way of the *Moon* from the *Sun* do form, we have one Angle which is the Inclination of the way of the *Moon* from the *Sun* to the Ecliptick, and its Baſe which is the diſtance of the Circle of Latitude from the *Node*, and therefore we can find the other Acute Angle.

LECTURE XIII.

Of the Projection of the Moon's *Shadow on the Disk of the* Earth.

IF a Right Line be Projected on a Plane that is Parallel to it, by letting fall from all its Points Perpendiculars on the Plane, the Projection, or the place where all Perpendiculars meet with the Plane, will be a Right Line, Parallel and equal to the former Line which was Projected. For the Perpendiculars that fall from the extremities of the Right Line are Parallel and equal, and therefore the Lines which join them will be Parallel and equal.

HENCE if two Right Lines touching one another be Parallel to any Plane, the Projections of theſe two Lines upon that Plane will contain an Angle equal to the Angle the Lines themſelves make together, this is plain by *Prop.* 10 Book XI of *Euclid.* Hence all Plane Figures projected on a Plane Parallel to themſelves have for their Projections Figures exactly ſimilar and equal to themſelves.

Plate X. Fig. 1.

BUT if a Line be inclined to any Plane, its Projection upon that Plane made by letting fall from it Perpendiculars to the Plane, will be to the Line it ſelf, as the Coſine of the Inclination of the Line is to the Radius. For let A B be a Line inclined to the Plane, and let D E repreſent the Plane. Letting fall from the Points A and B, the Perpendiculars A *a* B *b*, *a b* will be the Projection of the Line A B; to which if we draw thro' B the Parallel Line B C, meeting with the Perpendicular A *a* in C, this Line B C is equal to *a b*: but B C is to A B, as the Sine of the Angle C A B, or the Coſine of the Angle A B C to the Radius, that is, as the Coſine of the Angle of Inclination is to the Radius, ſo is *a b* to A B. Hence it follows, that every Figure, whoſe Plane is Perpendicular to the Plane of the Projection, is Projected in a Right Line. For the Perpendiculars from every Point of the Figure will all fall upon the common Interſection of the Plane of the Figure with the Plane of the Projection. Such a Projection of Lines and Figures is called an *Orthographical* Projection.

An Orthographical Projection what?

IF we imagine a Plane to paſs thro' the Center of the *Earth*, ſo that the Line which joins the Centers of the *Sun* and *Earth*, may be Perpendicular to this Plane, it will make on the Surface of the *Earth* a Circle, which will ſeperate the illuminated Hemiſphere of the *Earth* from the dark. This Circle we before called the Circle bounding Light and darkneſs, but we will now call it the illuminated Disk; which Disk is directly ſeen by a Spectator placed at the diſtance of the *Moon*, in the Right Line which joins the Centers of the *Sun* and *Earth*. Upon this Circle the *Earth*'s Equator, its Parallels, *Poles*, and all the other Circles which we imagined, are to be ſuppoſed Projected *Orthographically*. For all Lines drawn from the Center

The Disk of the Earth.

The Orthographical Projection on the Disk.

Center of the *Sun* to every ſingle Point of the Disk, are to be accounted Parallel; and therefore ſince that Line which is drawn to the Center of the Disk is perpendicular to it, all the reſt will be perpendicular to it; and therefore all Lines drawn from the Center of the *Sun*, and paſſing thro' every Point of any Circle upon the *Earth*'s Surface, when they are produced will be perpendicular to the Plane of the Disk. Moreover a Spectator in the *Moon* will ſee all Countries, Cities and Towns, to move upon the Disk, which Motion is occaſioned by the Rotation of the *Earth* round its *Axis*, and every Point will have its way on the Disk: for by the Diurnal gyration all places deſcribe either the Æquator, or one of its Parallels; and if the *Sun* be in the Plane of the Æquinoctial, or rather if the Plane of Æquinoctial paſſes thro' the *Sun*, the Æquinoctial and all its Parallels are in that caſe projected into Right Lines, for they will all be Perpendicular to the Disk, or the Plane of the Projection. But in other Poſitions the Projections of theſe Circles will be Ellipſes, which are the ways that all the places of the *Earth* are ſeen to move in on the Disk: Now if thro' the *Pole* and the *Sun* there be a great Circle drawn which cuts the *Earth*, and this Circle be Projected on the Disk, we ſhall have an Univerſal Meridian, to which when any place is obſerved to come, the Inhabitants of that place will have mid-day. And when any place is firſt ſeen to touch the *Weſtern* Limb, or edge of the Disk, the Inhabitants of that place will then ſee the *Sun* ariſing upon them. But a Spectator at the *Moon* will ſee the place to riſe and come upon the Disk, and will ſee it move towards the *Eaſt*: And as ſoon as it has paſſed the Univerſal Meridian, the place then being gone to the *Eaſtward*; the *Sun* ſeen out of the *Earth* from the place will appear to move *Weſtward*. But when the place comes to the *Eaſtern* edge of the

The Univerſal Meridian.

the Disk, our Spectator in the *Moon* will obſerve the place to ſett in the Disk, and hide itſelf in the dark ſide; but the Inhabitants of that place upon the *Earth*'s Surface will ſee the *Sun* ſett in the *Weſt*, and withdraw himſelf out of Sight.

The bigneſs of the Disk determined.

THE bigneſs of the Disk is to be eſtimated by the Angle under which the *Earth* is ſeen from the *Moon*, and is of the ſame quantity with the *Horizontal Parallax* of the *Moon*. And if from the *Moon* there be let fall a Perpendicular upon the Plane of the Eccliptick, which Meaſures the diſtance of the *Moon* from the Ecliptick, this Line being Parallel to the Plane of the Disk, will be Projected into a Line equal and Parallel to itsſelf, and the Angle under which the Projection of this Line appears from the *Moon*, will be equal to the Angle under which the ſame Line is ſeen from the *Earth*; for equal Right Lines at equal diſtances being ſeen directly, appear under equal Angles.

The Projection of the Moon's way on the Disk.

The way of the *Moon* from the *Sun*, if ſuch a ſmall Portion of it be taken as is turned towards the Disk in the time of an Eclipſe, may be eſteemed as a Right Line, and will be Projected upon the Disk into a Right Line which is equal to itſelf, and its Projection with the Projection of the Circle of Latitude will contain the ſame Angle, that theſe two Lines make in the Heavens: The Spectator in the *Moon* will ſee this Line to be deſcribed upon the Plane of the Disk, by the Center of the Shadow and of the *Penumbra* which coincide.

Plate X. Fig. 2, 3, 4, 5.

LET now the Circle DGK repreſent the Disk of the *Earth*, whoſe Semidiameter let us ſuppoſe to be divided into as many parts as the *Horizontal Parallax* of the *Moon* contains Minutes and Seconds. Let the Line NT repreſent the diſtance of the *Moon* from the Ecliptick in the time of *New Moon*, Projected on the Plane of the Disk, which alſo muſt conſiſt of as many parts as the Latitude of the *Moon* contains Minutes; and let likewiſe K ☊ be a Portion of the Ecliptick, ☊ *l* a Portion of the Way of the *Moon* from the *Sun*, both projected on the Plane of the Disk. From the Center T, let fall on the way of the Shadow a Perpendicular T V; this Line will meaſure the leaſt Diſtance that is between the Centers of the Disk and Shadow. At the Center V deſcribe a ſmall Circle, whoſe Semidiameter may be equal to the Difference of the apparent Semidiameters of the *Moon* and *Sun*; this Circle will repreſent the Breadth of the Shadow; for we have ſhewed, that this Shadow ſeen from the *Moon* at the Diſtance of the *Earth*, was equal to the Exceſs whereby the apparent Diameter of the *Moon* exceeds that of the *Sun*. Again, let there be deſcribed another Circle H M, at the Center V, whoſe Semidiameter V H bears the ſame Proportion to the Semidiameter of the Disk, as the Sum of the Semidiameters of both *Sun* and *Moon* bears to the apparent Semidiameter of the *Earth* ſeen from the *Moon*; or, which is the ſame, to the *Horizontal Parallax* of the *Moon*: This Circle will repreſent the *Penumbra* projected at its ſhorteſt Diſtance from the Center of the Disk; for we have ſhewed, that the apparent Semidiameter of the *Penumbra* ſeen from the *Moon*, was equal to the Semidiameters of both *Sun* and *Moon*. And therefore if this Circle does not touch the Disk, there can be no *Eclipſe*; that is, if the Diſtance V T be greater than the Sum of the Semidiameters of the Disk and the *Penumbra*, or, which is the ſame, greater than the Sum of the Semidiameters of the *Sun* and *Moon* and of the *Horizontal Parallax* of the *Moon*, there can be no *Eclipſe*. But if the Diſtance V T be equal to this Sum, the *Penumbra* will juſt touch the Disk, without obſcuring the *Sun*, or any part thereof: But if V T be leſs than this Sum, that is, if it be leſs than VM and TR, the *Penumbra* will cover ſome part of the Disk; and thoſe that lie within the Segment R Z M Y, will ſee at leaſt a partial Eclipſe of the *Sun*. But if the Diſtance V T be leſs than the Difference of

The Proportion of the Moon's *Latitude.*

The Shadow projected.

The Penumbra *projected.*

When there can be no Eclipſe of the Earth.

When there muſt be an Eclipſe.

Total Eclipſes of the Sun.

the Semidiameter of the Disk and the Semidiameter of the Shadow, then the Shadow will cover ſome part of the Disk, and make a total *Eclipſe* of the *Sun* in all thoſe Places it paſſes over. Theſe total *Eclipſes* are always but for a ſmall portion of Time, becauſe the Diameter of the total Shade is but ſmall; the apparent Diameter of the *Moon* never exceeding the apparent Diameter of the *Sun*, but by a very ſmall matter, which is ſeldom equal to two Minutes; which ſpace the Center of the Shade paſſes over on the Disk in the ſpace of four Minutes of Time; but yet the Stay that it may make on any Place may be longer than this, upon the Account of the Motion of the Place which follows the Shade.

The Ecliptick Limits.

Hence we may know the *Ecliptick Limits*, or the Diſtance of the *Moon* from the *Nodes* at the time of *New Moon*, ſo that an Eclipſe of the *Sun* may be poſſible: for let the Circle R O G repreſent the Disk of the *Earth*, ☊ T K and ☊ N the Projections of a Portion of the Ecliptick, and of the Way of the *Moon* from the *Sun* upon the Plane of the Disk: And let T V be the leaſt Diſtance of the Center of the Disk and Shadow, which ſuppoſe equal to the Sum of the Semidiameters of the Disk and *Penumbra*. Then in the Rectangular Triangle ☊ T V, we have the Side T V; which, when it is biggeſt, is about 94½ Minutes: We have likewiſe the Angle at ☊, which, when it is leaſt, is 5 Degrees and 30 Minutes; from whence we ſhall find ☊ T equal to 986 Minutes, or to 16 Degrees and 26 Minutes. And ſince in this Caſe the *Penumbra* only touches the Disk, it is plain, that there can be no Eclipſe, unleſs the *New-Moon*, be nearer to the *Node* than 16 Degrees and 26 Minutes.

Plate X. Fig. 6.

Let the Circle R K G, as before, repreſent the Disk of the *Earth*, ☊ T K a Portion of the Ecliptick projected on the Plane of the Disk, ☊ *l* the Way of the *Moon*'s Shadow on the Disk; T N the Latitude of the *Moon*, and T V the ſhorteſt Diſtance of the Centers of the Shadow and Disk;

let the Circle O P Q be the *Penumbra* moving from D by V to *L*; in the middle of which is a ſmall Circle repreſenting the Shadow: And let us ſuppoſe we know the Time of the Conjunction, that is, when the Center of the Shadow is in N, which we find by Aſtronomical Tables; by that means we can find the Time when the Center of the Shade is in V, that is the Time of the middle of the general Eclipſe. For in the Rectangled Triangle T V N, we have T N the Latitude of the *Moon*, and the Angle T N V, which the Circle of Latitude makes with the Way of the *Moon* from the *Sun*; and therefore we can find V N and T V. But by the Horary Motion of the *Moon* from the *Sun*, we can find out the Time the Shadow will paſs through the ſpace N V; and this Time either added or ſubſtracted from the Time of the Conjunction, will give the Time of the middle of the Eclipſe. Moreover, in the Triangle D V T, right-angled at V, we have the Side D T, which is the Sum of the Semidiameters of the *Disk* and *Penumbra*, and the Side T V the ſhorteſt Diſtance of the Shade from the Center of the Disk; therefore we can find out the Side D V, and by it the Time when the Shade enters the Disk; and from that we ſhall have the Semiduration, or half the Time the Eclipſe continues upon the Disk. After the ſame manner we ſhall find the Time when the Shade leaves the Disk, or the Time of the End of the Eclipſe.

The Time of the middle of the Eclipſe.

The Semiduration.

HAVING the Place of the *Sun* in the Ecliptick for any Moment of time, we can thereby find the Place on the Surface of the *Earth*, upon which the *Sun* at that time is Vertical: For the Latitude of the Place is equal to the Declination of the *Sun* at that time; and its Longitude is found by turning the time from the Meridian into Degrees and Minutes of the Equator, allowing for every Hour 15 Degrees, and for every Minute of an Hour 15 Minutes of a Degree. For Example, The Longitude of a Place, in whoſe *Vertex* the *Sun* is, when at *Oxford* we reckon Nine and an

To find the Place to which the Sun is vertical.

Lecture XIII.

half in the Morning, is known by ſubſtracting 9 and a half from 12, and then there will remain 2 Hours and 30 Minutes, which multiplied by 15 make 37 Degrees and 30 Minutes. And therefore that Place will be 37 Degrees and 30 Minutes to the *Eaſt* of *Oxford.*

Plate X. Fig. 7.

The Elevation of the Earth's *Pole above the Disk.*

LET the Circle F R K repreſent the Disk, as before, F T K a Portion of the Ecliptick projected on the Disk; on which from the Center erect the Perpendicular T R: this Line will be the Projection of the *Axis* of the Ecliptick, and the Point R of its Pole. Let the Point P be the Projection of the Pole of the *Earth*: Through T and the Pole P let us imagine a Circle to paſs, and to be projected on the Disk; this Circle will repreſent the Univerſal Meridian, and the Elevation of the Pole above the Plane of the Disk will always be equal to the Declination of the *Sun.* For the Arch of the Meridian between the *Sun* and the *Periphery* of the Disk, is a Quadrant of a Circle; and the Arch of the Meridian between the Æquator and the Pole is likewiſe a Quadrant: Wherefore taking away from equal Arches the common Arch T P, there will remain P S, the Elevation of the Pole above the Disk, equal to the Diſtance of the *Sun* from the Æquator.

To find the Poſition of the Meridian, which paſſes thro' the Sun.

IT is here to be obſerved, that when the *Sun* is in the Signs ♑ ♒ ♓ ♈ ♉ ♊, or rather when the *Earth* is in the oppoſite Signs, the Point S, wherein the Univerſal Meridian cuts the Limb of the Disk, will fall towards the Right Hand of the Pole of the Ecliptick. But when the *Sun* is in the other ſix Signs, the Point S falls upon the other Side of the Pole of the Ecliptick, contrary to what happens when the Projection is ſuppoſed to be made in a Plane parallel to the Disk at the Orbit of the *Moon.*

FOR to find the Angle RTS, or the Arch of the Disk intercepted between the Pole of the Ecliptick and the Point S. In the Right-angled ſpherical Triangle R P S, we have the Arch R P, the Diſtance of the Poles of the Ecliptick and Æquator 23½ Degrees; alſo the Side P S, which is equal to the Declination of the *Sun*: Wherefore, by *Trigonometry*, we may find the Side R S, or the Meaſure of the Angle R T S.

To find the Place of the Earth *which is firſt touched by the* Penumbra.

FOR to find the Place upon the *Earth*'s Surface Q, where the *Sun* riſing begins to be in an Eclipſe in its upper Limb, and where the Shadow enters the Disk. Draw through the Pole the Meridian P Q, to the Point Q where the *Penumbra* firſt touches the Disk. And firſt in the right lined Triangle D T V, having D T and T V, we may know the Angle D T V; to which if we add or ſubſtract a given Angle V T P, which is the Sum or Difference of two known Angles V T N and N T P, we ſhall have the Angle Q T P. And then in the ſpherical Triangle on the Surface of the *Earth* S P Q, which is Right-angled at S, we have S P equal to the Declination of the *Sun*; and the Arch S Q which is the Meaſure of the known Angle S T Q; from whence we may find the Arch P Q the Complement of the Latitude of the Place Q, and the Angle S P Q, whoſe Complement to two Rights is the Angle Q P T, contained between the Meridian of the Place Q and the Meridian of that Place to which the *Sun* is then vertical, and is the Meaſure of the Diſtance of the Meridian of the Place Q, from that of the Place which has the *Sun* in the Meridian at that time. But we know the Place which has the *Sun* at that time in its Meridian; wherefore we know likewiſe the Meridian or Longitude of the Place Q: But its Co-Latitude P Q was before found out. Having therefore both the Longitude and Latitude of that Place, the Place itſelf muſt be known.

BY the ſame Method we can find out the Place of the *Earth*, which is firſt involved in the total Shadow. And by a like Proceſs we may find out the Place M on the Surface of the *Earth*, which is under the total Shadow at any Point of Time, either before or after the middle of the Eclipſe. For the time being known, we may find by the Horary Motion of the *Moon* from the *Sun*, the

Line M V and the Point M, where the Center of the Shadow lies: and in the right-lined Triangle M V T, having M V and V T, we may find M T and the Angle M T V; to which if you add or ſubſtract the known Angle V T P, we ſhall have the Angle M T P. But M T is the Sine of an Arch of the vertical Circle which paſſes through M and the Point of the *Earth*'s Surface directly under the *Sun*, the Semidiameter of the Disk being made the Radius. And therefore if we ſay; As the Semidiameter of the Disk is to M T, So the Radius to the Sign of an Arch: The Arch found out by this Proportion will be the Diſtance of the *Sun* from the *Vertex* M. And therefore in the Spherical Triangle on the Surface of the *Earth* M P T, we have P T the Diſtance of the *Sun* from the Pole, and M T the Diſtance of the *Sun* from the *Vertex*, and the Angle M T P. Hence we can find M P, which is the Complement of the Latitude of the Place, and the Angle M P T, which ſhews the Difference of the Meridians of the Place M, and of that Place to which the *Sun* at that time is vertical; which Place by the time is known: and therefore we can find the Place M. And by this Method we may find ſeveral Places over which the Shade does paſs; and if they be joined by Lines, we ſhall have the Way of the Shade upon the Surface of the *Earth*.

The Determination of the Place involved by the Shadow, for any given Time.

The Portion of the Solar Disk obſcured by the Eclipſe.

THE Portion of the Diameter of the *Sun* obſcured by the *Moon*, is known by the Situation of the *Spectator* within the *Penumbra*, or by his Diſtance from the Center of the Shade. For let A S B be the Diameter of the *Sun*, parallel to the Diameter of the *Penumbra* E F; draw the Line M C B, touching the ſuperior Edges of both *Sun* and *Moon*; and let F C A alſo touch the inferior Margin of the *Sun*: Then the Angle A C B is equal to the apparent Diameter of the *Sun*; and the Triangles A C B and M C F are ſimilar. Suppoſe then a *Spectator* within the *Penumbra* at G; draw the Line G C P, touching the Globe of the *Moon*, which nearly paſſes through the former

Plate X. Fig. 8.

mer Point C, and cuts off A P, that part of the *Sun*'s Diameter, which is obſcured by the *Moon*, to the *Spectator* in G. But the right Line G P, ſince it very nearly paſſes through the *Vertex* of the Triangles M C F and A C B, will divide the Baſes A B and M F in a like Proportion. And therefore A P is to A B as F G to M F; that is, the obſcured Portion of the *Sun*'s Diameter is to the whole Diameter, as the Diſtance of the Place from the Edge of the *Penumbra*, which is F G, is to F M the Semidiameter of the *Penumbra* diminiſhed by the Semidiameter of the total Shadow.

The Quantity of the Eclipſe eſtimated by Digits.

THE *Aſtronomers* commonly divide the Diameters of both Solar and Lunar Disks into twelve equal Parts, which they call *Digits*; and by them they meaſure the Quantity of the Obſcuration. And they ſay, the Eclipſe is of ſo many *Digits*, as the obſcured Portion conſiſts of ſuch Parts.

Having the Poſition of the Place on the Disk, to find the Phaſis *of the Eclipſe.*

IF we know the Poſition of any Place upon the Disk for any Point of Time, and it be deſired to find the *Phaſis* of the Eclipſe for that time, as it is ſeen from the Place; it is to be found in this manner. Let S be the Poſition of the Place on the Disk; find out for that Point of Time, the Place of the Center of the Shade in its Path; which let it be M. At the Center M, with a Semidiameter equal to the Semidiameter of the *Moon*, deſcribe the Circle A F L: Alſo at the Center S, with a Semidiameter S B, equal to that of the *Sun*, deſcribe the Circle E F G, which the Circle A F L cuts in E and F; then E B F A will be that part of the *Sun* which is covered by the *Moon* from a *Spectator* in S. For produce the Semidiameter of the *Moon* M A through S, that A D may be equal to the Semidiameter of the *Sun*, which is equal to B S; and then M D will be equal to the Sum of the Semidiameters of both *Sun* and *Moon*; and therefore it will be equal to the Semidiameter of the *Penumbra*: And the Diſtance of the Place from the Edge of the *Penumbra* is S D: And becauſe B S is equal to A D, A B will be equal to S D. Take A N equal to the Semidiameter of the *Sun*,

Plate X. Fig. 9.

and then M N will be equal to the Difference of the Semidiameters of the *Sun* and *Moon*, which is equal to the Semidiameter of the total Shadow. But we ſhewed, that S D was to D N, as A B the part of the *Sun*'s Diameter obſcured was to the *Sun*'s Diameter. But A B is equal to S D, and D N is equal to D A and A N, which are equal to two Semidiameters of the *Sun*, or to one Diameter of the *Sun*. Therefore A B is to the Diameter of the *Sun*, as S D the Diſtance of the Place from the Edge of the *Penumbra*, is to D N, which is the Semidiameter of the *Penumbra* diminiſhed by the Semidiameter of the total Shadow. And therefore it is plain, that A B muſt repreſent the Portion of the *Sun*'s Diameter, which is then ſeen to be obſcured.

HENCE alſo is determined the Poſition of the *Cuſpides*, Points or Horns of the Eclipſe; for by drawing the Vertical Circle T S G, the Arches G E, G F, ſhow the Diſtance of the Points from the ſupreme or higheſt Point of the *Sun*'s Limb.

The Velocity of the Shadow on the Disk.

IF the Velocity wherewith the Shadow goes over the Disk, be enquired for, it muſt be obſerved, that the way of the *Moon* from the *Sun* is projected on the Disk in a Line parallel and equal to itſelf; which Line is deſcribed by the Motion of the Shadow: And therefore the Velocity of the Center of the Shade is equal to the Motion of the *Moon* from the *Sun*. Now the Motion of the *Moon* form the *Sun*, is about $30\frac{1}{2}$ Minutes in an Hour; though it is ſometimes more, and ſometimes leſs. And therefore the ſpace, which the Center of the Shade moves through in an Hour, is about $30\frac{1}{2}$ Minutes of the Lunar Orbit. Now the Semidiameter of the Lunar Orbit is about 60 Semidiameters of the *Earth*; and therefore one Minute of the Orbit of the *Moon* is as much as 60 on a great Circle of the *Earth*, or as much as one Degree, that is, 69 *Engliſh* Miles. And therefore $30\frac{1}{2}$ Minutes are equivalent to 2104 *Engliſh* Miles; which ſpace the Shade moves through on the Disk in one Hour. But though

Plate X

front. p. 138.

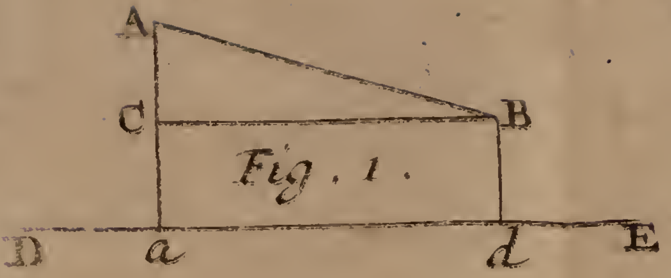


Fig. 1.

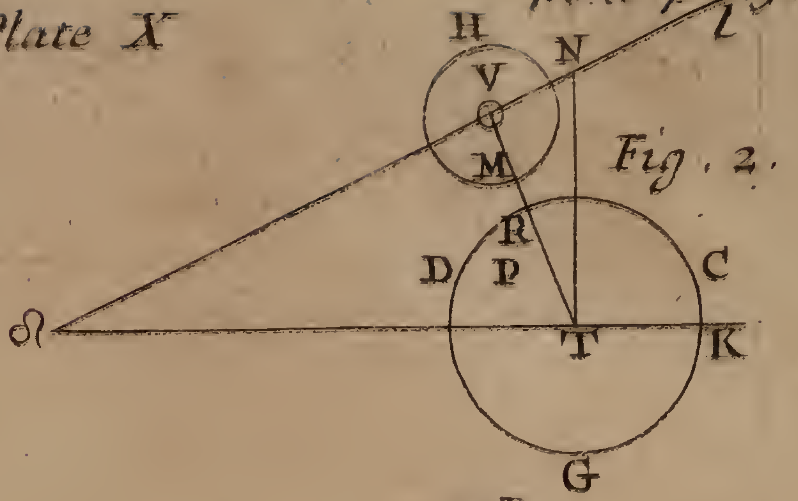


Fig. 2.

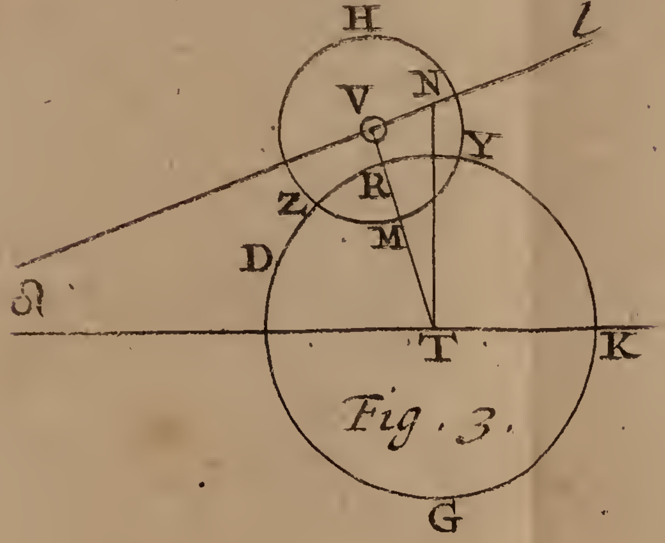
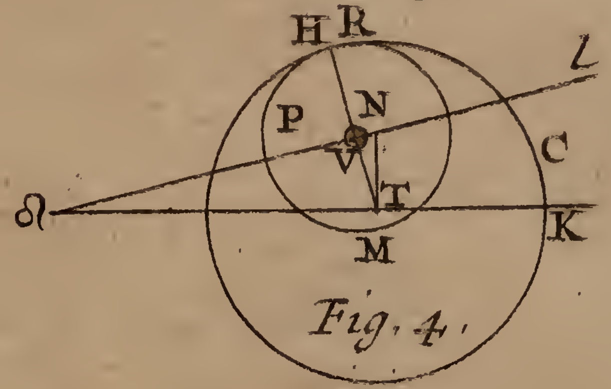


Fig. 3.



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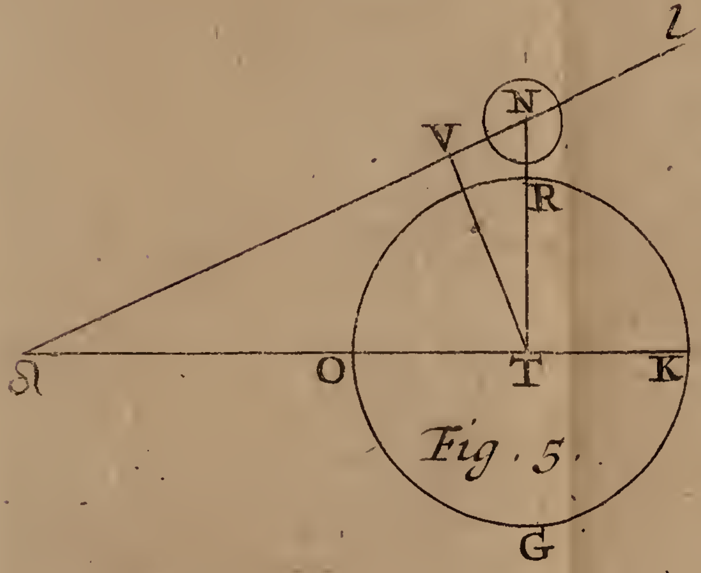
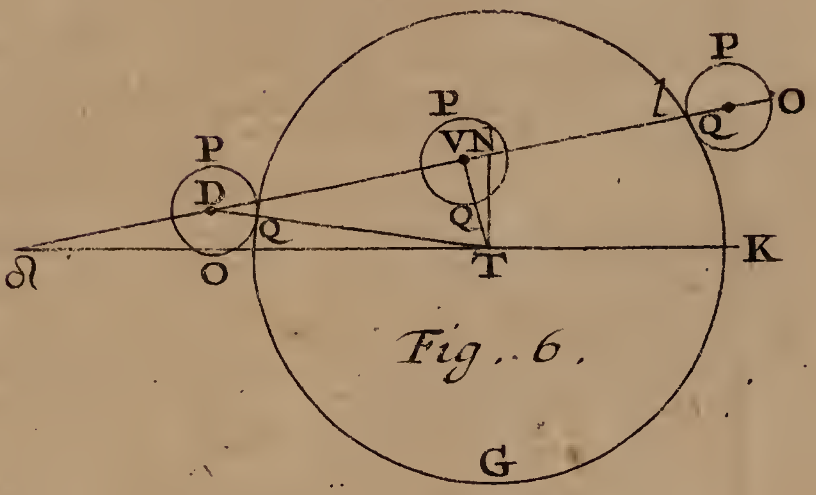


Fig. 5.



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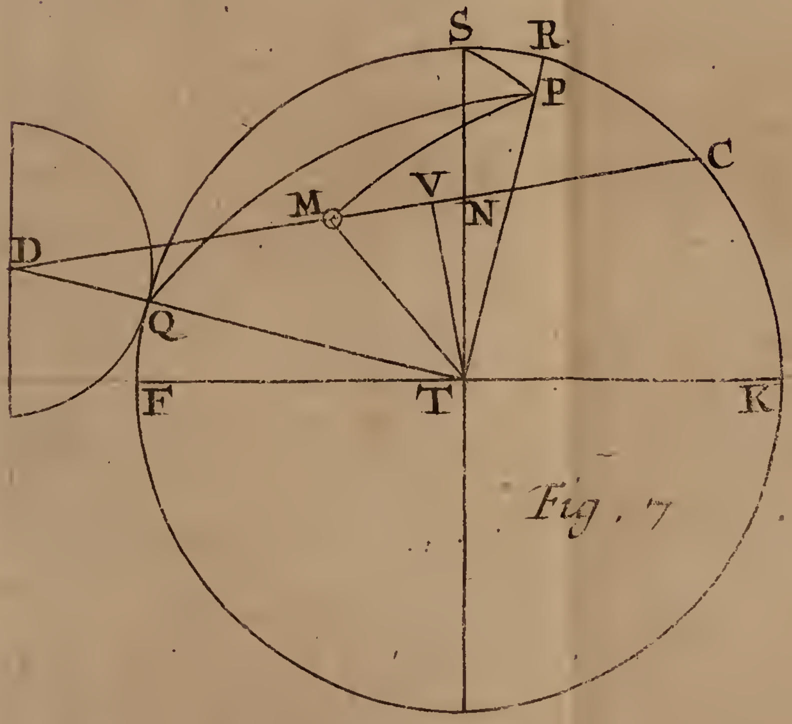


Fig. 7

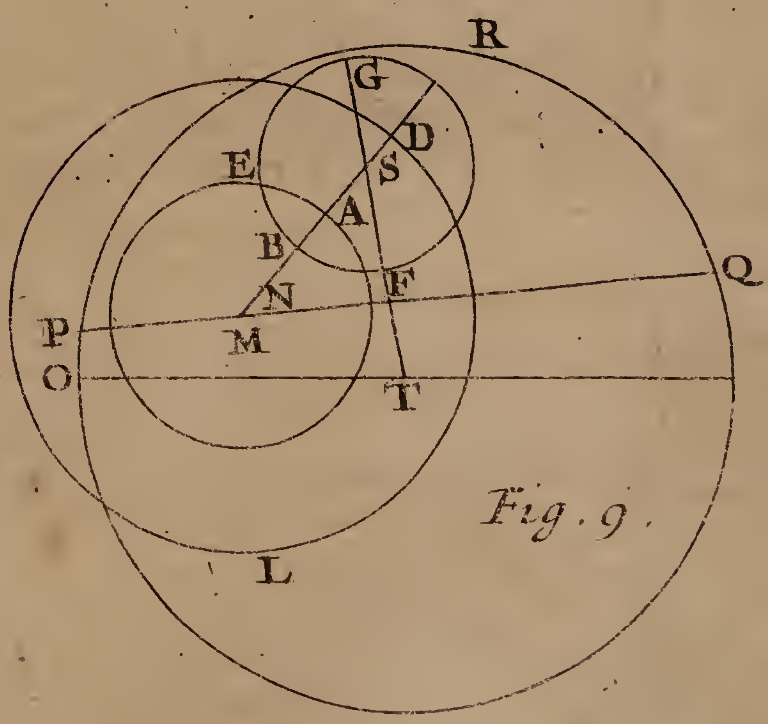


Fig. 9.

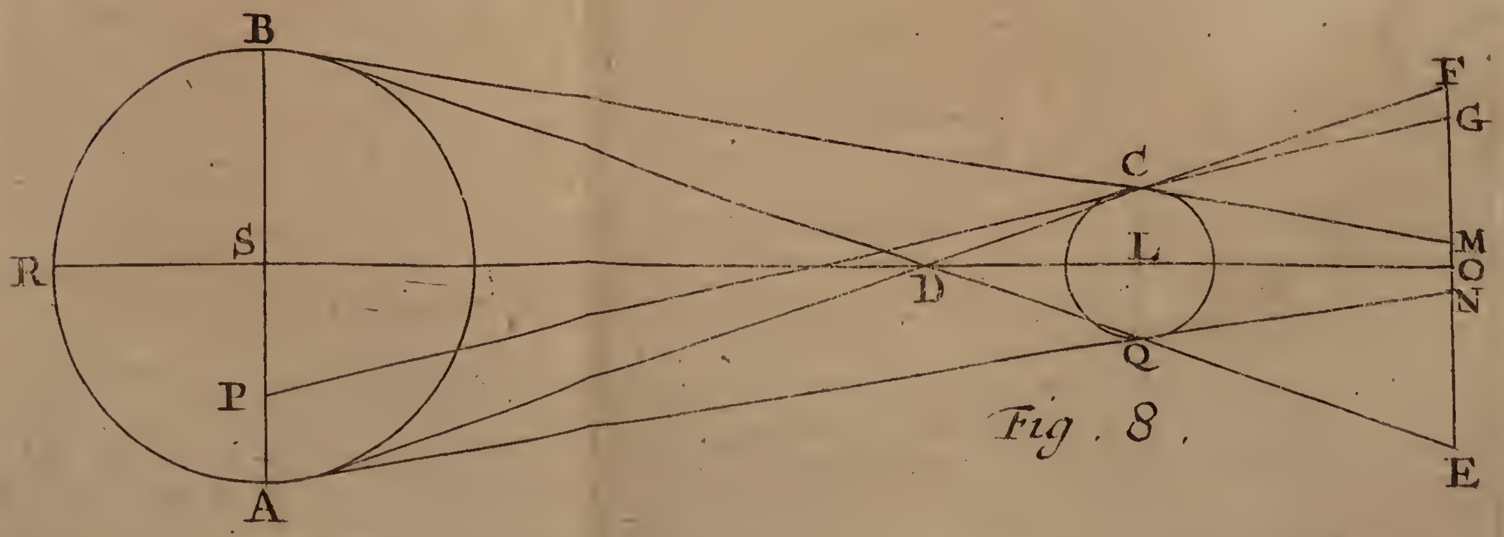


Fig. 8.

this be the Velocity of the Shadow on the Diſk, yet the Velocity whereby the Shade recedes from any given Place on the *Earth*'s Surface, is leſs than it; by reaſon that while the Shadow moves from the *Eaſt* to the *Weſt*, all the Places of the *Earth* are likewiſe carried by the Rotation of the *Earth* the ſame way: And therefore following the Motion of the Shadow with a ſlower pace, they diminiſh the Velocity whereby the Shade moves from them.

LECTURE XIV.

A new Method of Computing Eclipſes of the Sun, *as they are to be obſerved from any given Place on the* Earth's *Surface.*

HITHERTO we have explained all the *Phaſes* and Appearances of a General Eclipſe, ſuch as a *Spectator* at the *Moon* would obſerve; and we have ſhewed the Methods whereby the Beginning, Middle, and End of an Univerſal Eclipſe may be determined. But this Beginning and End can be obſerved by only a few, who lie near the Edge of the Diſk, where the Shadow enters. In other Places lying towards the middle of the Diſk, there will be no Eclipſes ſeen, till ſometime after, when the Margin or Edge of the *Penumbra* comes to touch them. And the End will be when the oppoſite part of the *Penumbra* leaves them. And therefore, according to the different Situation of Places, the Quantity of the viſible Eclipſe will be different, as likewiſe their Beginning, End and Duration.

The Beginning of an Univerſal Eclipſe can be obſerved by very few.

And the Beginnings in particular Places are very different.

THEREFORE to compute the particular *Phaſes* of an Eclipſe, as it is to be obſerved from a certain

Lecture XIV. certain Place, we muſt here explain a new Method, whereby, without the troubleſom and tedious Calculations of *Parallaxes*, which all the *Aſtronomers* have made uſe of before, the particular *Phaſes* may be ſhown.

A new Method to compute the Phaſes *for a particular Place.*

Plate XI. Fig. 1.

LET therefore the Semicircle A E B, be half the Disk of the *Earth*, in whoſe Circumference is the Point E, which anſwers to the Pole of the Ecliptick. And let the Pole of the *Earth*, or the Æquator, be projected into P. Becauſe all the Places of the *Earth*, being carried by the Diurnal Rotation, deſcribes Circles, which are the Æquator or its Parallels; and all the Parallels, except in the *Æquinoxies*, are inclined to the Plane of the Disk, the Parallel which any Place deſcribes will be projected into an Ellipſe, which will be the Way or Path in which that Place will be ſeen to move by a *Spectator* at the *Moon*. Let therefore E X I I D be the Ellipſe in which the Parallel of any Place is projected on the Disk: And let the Points in which the Horary Circles cut the Parallels, be likewiſe projected: And let theſe Points be VI, VII, VIII, IX, X, XI, XII. I, II, III, IV, V, VI. So at Six in the Morning the Place on the *Earth*'s Surface will be ſeen on the Disk at VI; at the ſeventh Hour it will be at VII, at Eight of the Clock it will be at VIII, and at Nine it will be in the Point IX, and ſo on.

LET C T be a Portion of the Path of the Shadow received on the Plane of the Disk: And ſuppoſe the Center of the Shade at Two of the Clock to be in the Point 2; at Three of the Clock let the Place of the Shadow be 3; and at Four let it be in the Point 4, &c. At Two of the Clock the Seat of the *Spectator* on the Disk is II; and therefore his Diſtance from the Center of the Shadow is 2 II: But if we meaſure this Diſtance according to the Path of the Shadow, we muſt let fall from the Place a Perpendicular to the Path, which let be II L, and the Diſtance thus eſtimated will be 2 L; and the Point L will be the Poſition of the Place reduced to the Path of the Shadow.

At Three of the Clock the Shadow is at 3, and the Place at III, and their Diſtance is 3 III, which is leſs than the former Diſtance at Two. At the fourth Hour the Shadow is in 4, and the Place in IV. All which time the Shadow advances nearer to the Place, till at laſt the Edge of the *Penumbra* touches it, and then the Eclipſe will begin at that Place. At the fifth Hour, when the Center of the Shadow is at 5 and the Place is in V, it will be there more within the *Penumbra* than it was before, and the Shadow will be near the Place: But at Six the Shadow being at 6 and the Place at VI, the Shadow will have got to the *Eaſt* of the Place, which is then in the Point of the Disk at VI; and therefore the Center of the Shadow has paſſed by the Place, and the time of the ſhorteſt Diſtance between the Center of the Shadow and the Place, will be between the Hours of 5 and 6. After this time the Diſtance of the Shadow and Place will conſtantly grow greater, and at laſt the *Weſtern* Edge of the *Penumbra* will leave the Place, and there will be an End of the Eclipſe upon that Place. But by the following Method the Beginning, Middle, End and Duration of the Eclipſe will be more accurately determined. Upon which account we muſt firſt premiſe the two following Problems.

PROBLEM I.

To find upon the Disk of the Earth *the Poſition of a Place for any given Point of Time.*

LET the Semicircle A E B repreſent half the Disk, A B a Portion of the Ecliptick projected on the Disk, its *Axis* projected S E, meeting with the *Periphery* of the Disk in E, which will be the Pole of the Ecliptick on the *Earth*'s Surface. Let S P be the Line on which the *Axis* of the *Earth* is projected, and P the Projection of the Pole. As the *Radius* is to the *Sine* of the Latitude of the Place, ſo let S P be to S H, and the Point H will be the Projection

Plate XI. Fig. 2.

Lecture XIV.

jection of the Center of the Parallel. Through H draw H G equal to the Semidiameter of the Parallel, or to the *Sine* of the Diſtance of the Place from the Pole, which muſt be perpendicular to P S; this will be half the greateſt *Axe* of the Ellipſe into which the Parallel is projected. As the *Radius* is to the *Sine* of the Pole's Elevation above the Plane of the Disk, ſo let G H be to H L, and H L will be the leſſer half *Axis* of the Ellipſe. In G H take H Q, which has the ſame Proportion to G H that the *Sine* of the Angle which the Horary Circle and the Meridian make together, has to the *Radius*; and draw Q R perpendicular to G H: Alſo make the Proportion, As the *Radius* to the Co-ſine of the Angle which the Horary Circle and the Meridian make together, ſo the leſſer *Semiaxe* H L to a fourth, to be laid on the Line Q R from Q to R; and then the Point R will be the Poſition of the place on the Disk required at the Moment of the Time given.

THE ſame may be done by the Help of the Horary Circle.

Plate XI. Fig. 3.

LET A O B be half the Disk, P the Pole, S P the *Univerſal Meridian*, meeting with the Disk in G; and let F P O be the Horary Circle for the Moment of Time given. In the Right-angled Triangle P G O, we have P G the Elevation of the Pole above the Disk; and the Angle G P O, which the Horary Circle makes with the Meridian. Whence we ſhall find out the Angle G O P, the Inclination of the Horary Circle to the Plane of the Disk, and the Arches P O and G O; and therefore we have the Point O where the Horary Circle cuts the Disk. Draw S O, which will be the common Section of the Horary Circle with the Plane of the Disk. Let P F be the Complement of the Latitude of the place. And S O being the *Radius*, take S Q, equal to the *Sine* of an Arch, whoſe Complement is the Sum of two Arches that are known, *viz.* F P and P O; and let D be the Co-ſine of the ſame Arch whoſe *Sine* is S Q;

S Q. At Q upon O S erect the Perpendicular Q R, ſo that D may have the ſame Proportion to Q R, that the *Radius* has to the *Coſine* of the Inclination of the Horary Circle to the Plane of the Diſk, and R will be the Point which was deſired, and ſhews the Poſition of the place on the Diſk for the Time given.

The ſame thing may be likewiſe found out this way. Calculate (by the *Problems* demonſtrated in the *Spherical Doctrine*, and in the *Problems* to be found where the Uſe of the Globes is taught) for the Moment of Time given, the *Sun*'s Altitude, and the Angle between the Vertical and Hour-Circle at his Center, and make the Angle RSP equal thereto; and take S R equal to the *Sine* of the Complement of the Altitude, or the *Sine* of his Diſtance from the *Vertex*, S E being the *Radius*, and then R will be the Point required. By the ſame Methods for all other different Moments of Time, we can find out other Poſitions of the place on the Diſk. The Demonſtrations of all theſe Practices are eaſily deduced from the Laws of *Orthographical Projection*. Plate XI, Fig. 2.

PROBLEM II.

To find in an Eclipſe the Poſition of the Center of the Shadow on the Diſk, for any given Time.

Let A E B, as before, repreſent the *Semidiſk*, S E the *Axis* of the Ecliptick, C T the Path of the Shadow while it paſſes over the Diſk; and let it cut the *Axis* of the Ecliptick in N. Now when the Center of the Shadow is in N, then is the true Conjunction of the *Sun* and *Moon*, whoſe Time is known by Aſtronomical Tables. We have likewiſe by the ſame Tables the Horary Motion of the *Moon* from the *Sun*. Say, As the Horizontal *Parallax* of the *Moon* is to the Horary Motion of the *Moon* from the *Sun*; ſo is the Semidiameter of the Diſk to a fourth Line M: This will be the ſpace which the Shadow moves through upon the Plate XI, Fig. 4.

Diſk in an Hour. Then ſay, As one Hour is to the Time between the Conjunction and the Time for which the Poſition of the Shadow is ſought; ſo is the Line M to a fourth; this Line will ſhew the Diſtance of the Shadow in its proper Path, from the Point of Conjunction N, and conſequently the place of the Shadow for the Time given. Suppoſe the Hour which immediately precedes the Time of Conjunction, to be any Hour you pleaſe. For Example, let it be the fourth Hour; Say, As one Hour is to the Time between the fourth Hour and the Time of the Conjunction, ſo let the Line M be to another, which is N 4; and the Point 4 will be the Poſition of the Shadow at four of the Clock. Take likewiſe 4 3, 3 2, 4 5, 5 6, each equal to M; and the Points 2, 3, 4, 5, 6, will ſhew the place of the Shadow at the Hours 2, 3, 4, 5 and 6.

THESE things being premiſed, let AEB be half the Diſk, as before, CT the Path of the Shadow upon the Plane of the Diſk, which the *Axis* of the Ecliptick cuts in N; and when the Shadow comes to N, then is the Time of the true Conjunction. Let, for Example, the 2d be the Hour which immediately precedes the Time of the true Conjunction, and then mark in the Path of the Shadow its places at the Hours 1, 2, 3, 4, 5; and likewiſe at the ſame time mark the Situation of the Place on the Diſk at the ſame Hours; let them be I, II, III, IV, V. At one of the Clock the Diſtance of the Place and Shadow is 1 I; this by applying to a Scale of equal Parts, is to be meaſured, and taken in Numbers, and from thence deduct the Semidiameter of the *Penumbra* meaſured by the ſame Scale, and we have the Diſtance of the Place from the Edge of the *Penumbra*.

Plate XI. Fig. 4.

The Calculation of the Beginning of the Eclipſe.

AT Two of the Clock, after the ſame manner, take the Diſtance of the Edge of the *Penumbra* from the Place which is then in II; the Difference of theſe Diſtances, ſince the Edge of the *Penumbra* is in both Caſes more *Weſterly* than the place, is the Appropinquation or relative Motion of the Place to the Shadow in one Hour. Say then, As the Appropinquation of the Margin of the *Penumbra* to the place in one Hour is to the Diſtance of the ſaid Margin from the place at Two of the Clock, ſo one Hour is to the Diſtance of Time from Two till the Beginning of the Eclipſe; which time added to the ſecond Hour, ſhews the time when the Eclipſe begins.

The Calcution of the Time of greateſt Obſcuration.

FROM the Poſition of the place at II, to the Path of the Shadow, let fall the Perpendicular II *a* : And becauſe the Center of the Shadow is at 2, the Diſtance of it from the place reduced to the Path, is 2 *a*. Alſo at the third Hour the Poſition of the place being III, let fall from thence a Perpendicular III *b* on the Path; the Diſtance of the Shadow from the place reduced is 3 *b* : the Difference of theſe two Diſtances is the Acceſs of the Shadow to the place reduced, in the time of one Hour. Meaſure this Difference with a Scale, and by the Rule of Proportion ſay, As the Acceſs of the Shadow to the place reduced in one Hour, is to the Diſtance of the Shadow and Place reduced at Three of the Clock; ſo is one Hour, or 60 Minutes, to a fourth Time; which time added to the third Hour, gives the time of the middle of the Eclipſe, or of the greateſt Obſcuration.

The Calculation of the End of the Eclipſe.

AT four of the Clock the Center of the Shadow is in 4, and the place in IV; and becauſe 4 IV is leſs than the Semidiameter of the *Penumbra*, ſubſtract it from the Semidiameter, and there will remain the Diſtance of the place from the Edge of the *Penumbra*. Again, at Five of the Clock the Shadow is in 5 and the place in V; and their Diſtance is 5 V, which is greater than the Semidiameter of the *Penumbra*; and therefore the *Weſtern* Edge of the *Penumbra* is now more advanced towards the *Eaſt* than the Place is; and therefore before that time the *Penumbra* has quitted the Place, and the Eclipſe at an end. From the Diſtance 5 V, ſubduct the Semidiameter of the *Penumbra*, and there will be left the Diſtance between the Place and the *Weſtern* ſide of the *Penumbra*: And becauſe, in the former Caſe at Four of the Clock, the Edge was *Weſtward* of the place, and it has now got to the *Eaſt* of it, the relative Motion of the *Penumbra* and Place muſt be eſtimated by the Sum of theſe two Lines or Diſtances. Say then, As the Sum of theſe two Diſtances is to the Diſtance of the Edge of the *Penumbra* from the place at the fourth Hour; ſo is one Hour to a fourth Time; which Time added to 4 gives the Time when the *Penumbra* leaves the Place, or it will ſhew the End of the Eclipſe.

THE Motion of the Shadow in its Path is equable, at leaſt all the time of an Eclipſe it may be eſteemed equable. But the Motion of a Place upon the Disk is no ways equable, but towards the Edge of the Disk it is ſlower; when it comes towards the middle, it goes through larger ſpaces in equal time. Moreover, our Calculus ſuppoſes, that the relative Motion of the *Moon* and Shadow are equable; and the middle of the Eclipſe, or greateſt Obſcuration, to be where the Line which joins the Place and the Center of the *Penumbra*, is perpendicular to the Path of the Shadow; neither of which is preciſely true, and therefore there will ariſe ſome ſmall Error; but it may be corrected in this manner. At the time of the Beginning of the Eclipſe, find out the place of the Shadow, and likewiſe, for the ſame time, the Situation of the place upon the Disk. At the Center of the Shadow, with a Diſtance equal to the Semidiameter of the *Penumbra*, deſcribe a Circle; if this Circle paſſes through the Point the place is in, then is the Beginning of the Eclipſe rightly determined. But if this Circle does not paſs through the place, note the diſtance of the place and the *Periphery*, and take the relative Motion of the place and Margin of the *Penumbra* for half an Hour; and work again by the Rule of Proportion, as before, and we ſhall then have the true time of the Beginning of the Eclipſe. And by the ſame

Method we may correct the Error, that may ariſe in computing the End of the Eclipſe. And by this means we may have the Beginning and End of Eclipſes as accurately as by the common Method, which is by a troubleſom Calculation of the *Parallaxes*; where they likewiſe ſuppoſe, that the viſible Motion of the *Moon* is equable for a certain time; which, nevertheleſs, is as unequable as the Motion of a place upon the Disk is.

IF about the time of the middle of the Eclipſe, at the Center of the Shadow a Circle be deſcribed, whoſe *Radius* is equal to the Semidiameter of the *Moon*: And if likewiſe we deſcribe another Circle, whoſe Center is the place of the *Spectator*, and whoſe *Radius* is the Semidiameter of the *Sun*; the Interſections of theſe two Circles will ſhew the *Phaſis* at the greateſt Obſcuration.

The ſame may be performed by Trigonometry.

IF there be ſome who are not pleaſed with this mechanical way of meaſuring Lines and Diſtances by a Scale, they may compute all the Lines by *Trigonometry*, in the following manner. As before let A E B be the Disk of the *Earth*, P the Projection of the *Pole*, C N T the way of the Shadow, the Point 2 its Poſition at Two of the Clock; and, for the ſame time, let II be the Situation of the place of the *Spectator*. Let S E be the *Axis* of the Ecliptick, which cuts the Path of the Shadow in N; S N will be the Latitude of the *Moon* at the time of the *Conjunction*. From the Center of the Shadow and the Place draw the Lines 2 S, II S, to the Center of the Disk, and join 2 II: Then in the Right-lined Triangle 2 N S we have N S the Latitude of the *Moon*, and 2 N its diſtance from *Conjunction* at Two of the Clock. We have likewiſe the Angle 2 N S, which is the Inclination of the Path to the Circle of Latitude: Wherefore we can find out 2 S and the Angle 2 S N. Again, in the ſpherical Triangle P S II, we have the ſide P S the Complement of the *Sun's* Declination, and P II the Complement of the Latitude, together with the Angle S P II, which is known by the Time; by which we can find the

Plate XI. Fig. 5.

Arch S II, which is the diſtance of the *Sun* from the *Vertex*; and the *Sine* of this Arch is juſt equal to the diſtance S II, S E being made the *Radius*: we may alſo find the Angle P S II; to which if we add, or take away the known Angle P S E, we ſhall have the Angle N S II. But the Angle P N S was found out before; wherefore we have the whole Angle 2 S II. Laſtly, In the Right-lined Triangle 2 S II we have the two ſides 2 S and II S, and the Angle contained between the two ſides; and therefore by plain Trigonometry we may find the ſide 2 II, which was to be found out. Proceeding by this Method, there is no need for inquiring into the Poſitions of Place and Shadow on the Disk; for they are to be found out by a *Calculus* without Protraction.

To find the Longitude of Places by Obſervations of Solar Eclipſes.

THE Longitudes of places on the Surface of the *Earth* may be found out by Obſervations of Eclipſes of the *Sun*, as well as by thoſe of the *Moon*, *viz.* if we obſerve in that place whoſe Longitude is wanted, the Moment of time when the Eclipſe begins or ends: Let that, for Example, be at Five of the Clock; and at the Center V, with a Diſtance equal to the Semidiameter of the *Penumbra*, deſcribe an Arch of a Circle cutting the Path of the Shadow in *d*, that Point *d* will ſhew the place of the Center of the Shadow at that time. Meaſure the Diſtance N *d* with a Scale, which being given, together with the Motion of the *Moon* from the *Sun*, we ſhall find the time, in the place of the Obſervation, when the true *Conjunction* is celebrated. In like manner, by an Obſervation in any other place we may find when the ſame *Conjunction* is celebrated according to the time computed from the Meridian of that place; and the Difference of thoſe times being turned into Degrees and Minutes of the Equator, will ſhew the Difference of Longitude between thoſe two places.

IN Practice it is convenient to make the Semidiameter of the Disk ten Inches, that it may be divided by a Scale into a 1000 parts, which is

Plate XI fronting p. 148

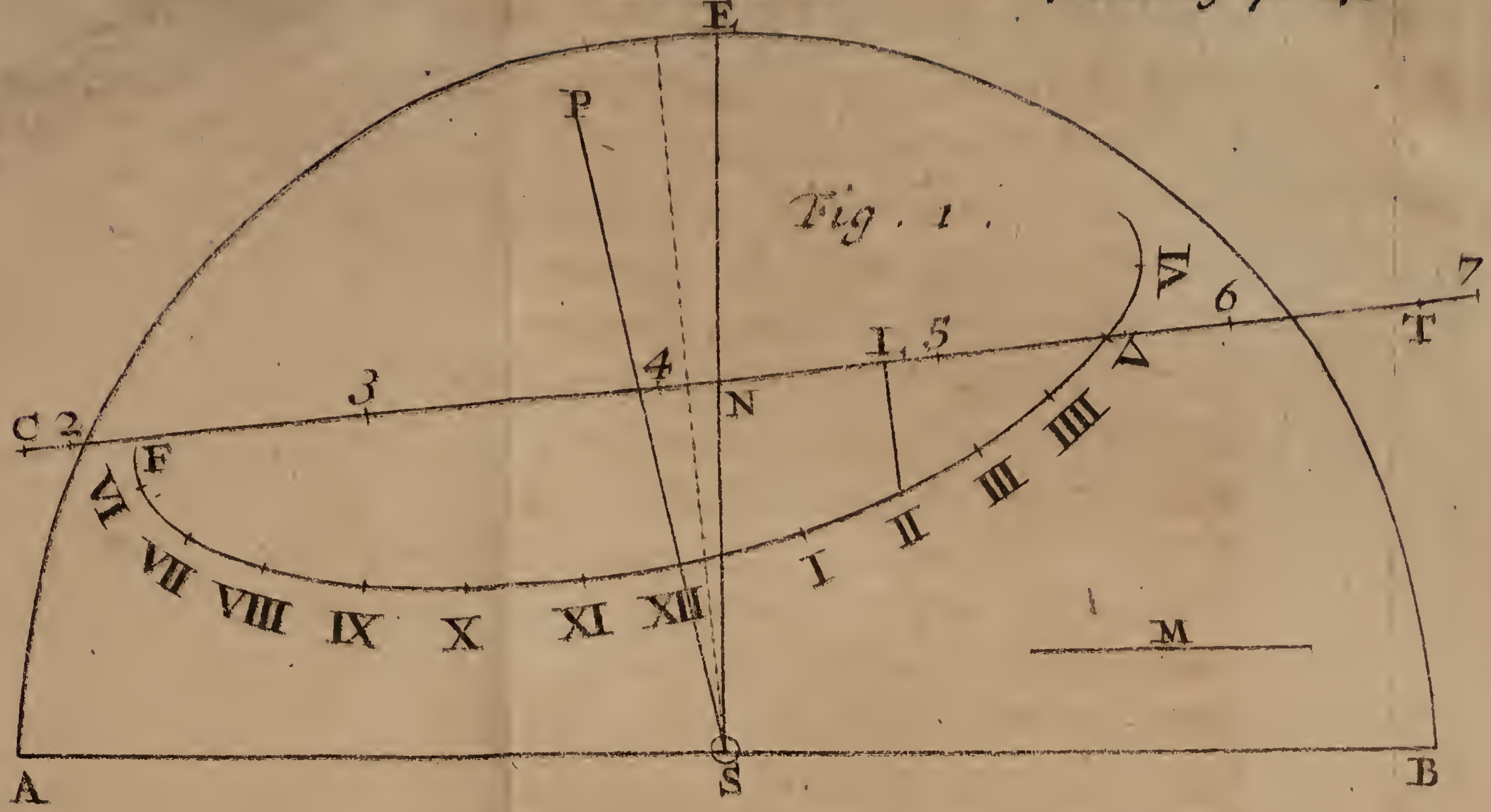
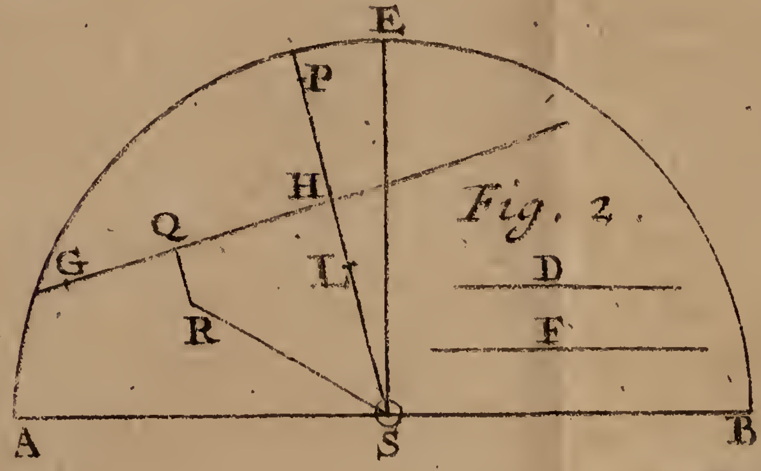


Fig. 1.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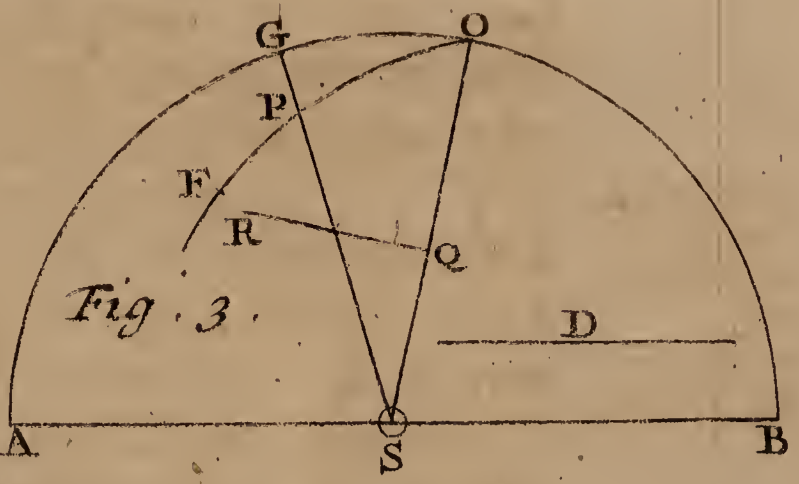


Fig. 3.

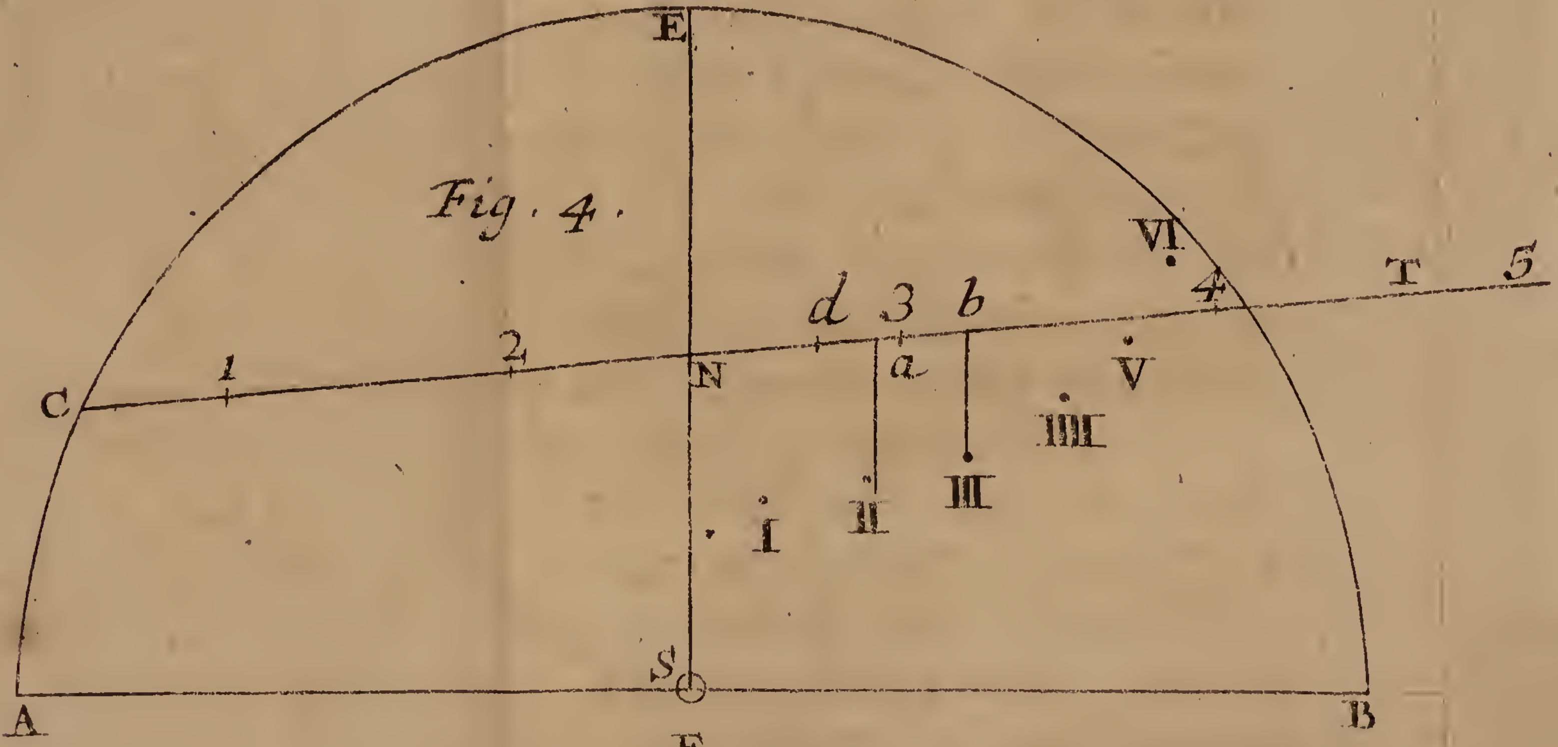


Fig. 4.

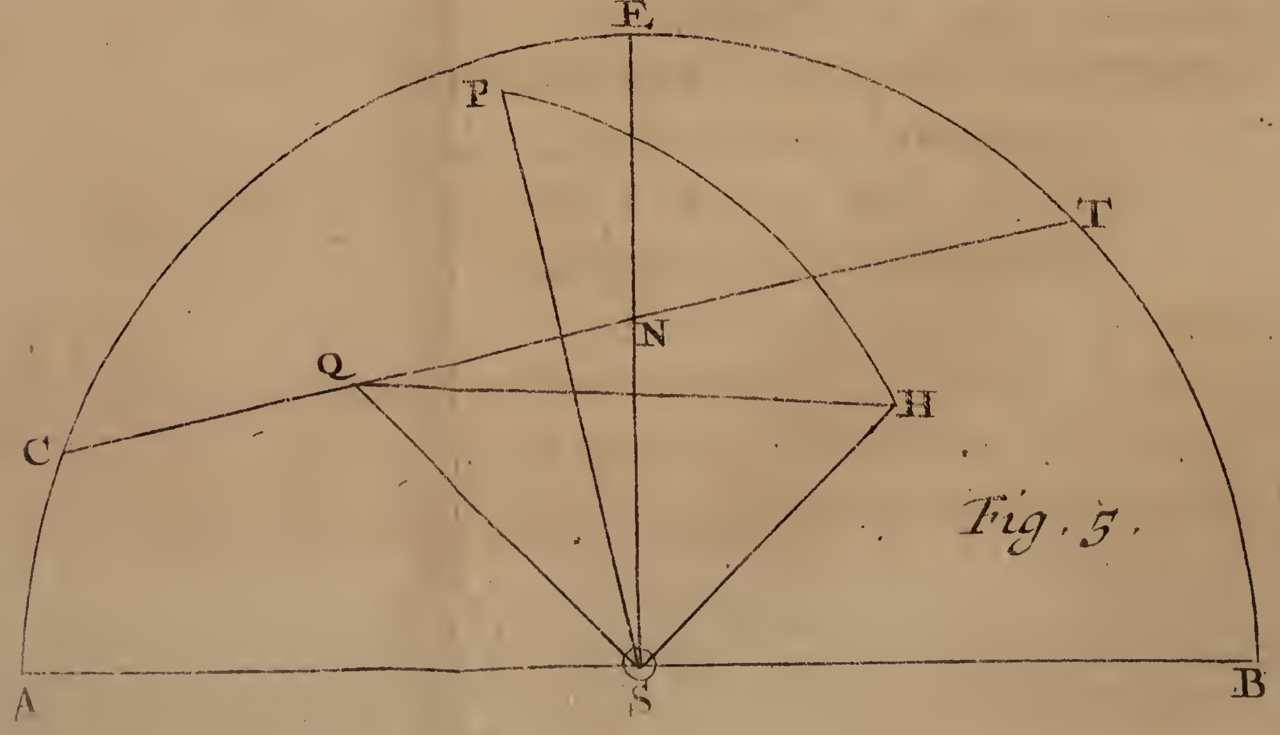


Fig. 5.

done by the Help of a Diagonal Scale; for this Number is the *Tabular Radius:* And let SN the Latitude of the *Moon*, and all the Lines whoſe Dimenſions are neceſſary to be known, be expreſſed by the ſame parts. For if we ſay, as the Horizontal *Parallax* of the *Moon*, which is expreſſed in Aſtronomical Tables in Minutes and Seconds, is to the *Moon*'s Latitude, ſo is 1000 to a fourth Number. And then we take the Line SN out of the Scale, whoſe Dimenſion is expreſſed by this fourth, this Line will repreſent the Latitude of the *Moon*. And in like manner we are to operate for to find out the length of the way the Shadow advances in an Hour in its Path. And now we have ſhewed a new way by which the Times and *Phaſes* of an Eclipſe are to be defined, as they are to be ſeen from a particular place, which does not require a frequent or repeated Calculation of the *Parallax*, for to have the viſible place of the *Moon* in the Heavens, both as to Longitude and Latitude; which Method is received by moſt *Aſtronomers*. But our Method is much eaſier, and, as I think, no leſs accurate. For in the common Method the different Poſitions of the Eclíptick in reſpect of the Horizon, which are always changing, will produce great Inequalities in the *Moon*'s Motion, and will make her conſtantly alter her place, both as to Longitude and Latitude: So likewiſe as the *Moon* aſcends or deſcends, the *Parallaxes* will always be changeable; and except we often compute them, it will be hard to eſcape falling into an Error.

BUT becauſe the Method of computing Eclipſes by *Parallaxes* is that which is generally made uſe of by the *Aſtronomers*, it will be convenient likewiſe to explain that Method. And here I ſuppoſe the Reader to be already inſtructed in the Doctrine of the *Parallaxes*, either by other Aſtronomical Books, where it is explained at length; or by what we ſhall after this ſay upon that Subject: And that being underſtood, the Principles on which the Calculation is founded are eaſily apprehended, though the Practice of the Rules is very difficult and tedious.

The common Method of computing Eclipſes of the Sun.

FIRST of all the viſible *Conjunction*, and the Way the *Moon* is then to take in the Heavens, are to be determined. For in this caſe the true and viſible *Conjunction* are very different both as to their Times and Places. The true place of the *Moon* is that which is ſeen from the Center of the *Earth*, the viſible Place is that which is ſeen from our Habitation on its Surface. Let the Semicircle A B C repreſent an Hemiſphere of the Globe of the *Earth*, whoſe Center is T; from whence draw the Right Line T L S through the *Moon* at L, and the *Sun* at S at a much greater Diſtance; and therefore ſince the Centers of the *Sun* and *Moon* are ſeen in the ſame Right Line from the Center of the *Earth*, they will appear in the ſame Point of the Heavens, and they will be in true *Conjunction*. But a *Spectator*, on the Surface of the *Earth* at A, will obſerve the Centers of the *Sun* and *Moon* in diſtinct Points of the Heavens, their Diſtance being the Arch S E. The Point where the Right Line T L drawn through the Centers of the *Earth* and *Moon* meets with the Heavens, is called the true Place of the *Moon*. But where a Right Line paſſing through the Eye of the *Spectator* on the Surface and the Center of the *Moon* meets with the Heavens, that Point is called the viſible or apparent place of the *Moon*. Let theſe Points be S and E; the Arch S E, which is the Diſtance between the true and apparent place, is called the *Moon*'s *Parallax*. Now becauſe the Points T and L, in reſpect of the immenſe Diſtance of the *fix'd Stars*, coincide, the Arch S E will be the ſame, whether its Center be conceived to be in L, or in T; and therefore the Arch S E is the Meaſure of the Angle S L E, or of the Angle A L T, which is equal to it. But the Angle A L T is the Angle under which the Semidiameter of the *Earth* A T, drawn thro' the place of the *Spectator*, is ſeen from the *Moon*: And therefore the *Parallax* of the *Moon* is always equal to this Angle. And this Angle is biggeſt

Plate XII. Fig. 1.

The Moon's *true Place.*

The Moon's *viſible Place.*

The Moon's Parallax.

biggeſt, when the Semidiameter is directly ſeen from the *Moon*; for then the Angle LAT is a Right Angle, and the *Moon* is ſeen in the Horizon, and therefore the *Horizontal Parallax* is greateſt of all. But if the *Moon* ſhould be in the *Vertex* F, the Angle ALT would there vaniſh; and the *Moon*'s true place would coincide with its apparent place, whence there would be no *Parallax*.

The Sun has no Parallax.

SINCE the *Parallax* of any celeſtial Body is always equal to the Angle under which the Semidiameter of the *Earth*, paſſing through the place of the *Spectator*, is ſeen from that Body, there will be no ſenſible *Parallax* of the *Sun*. For as I have frequently ſaid, the *Earth* ſeen from the *Sun* appears no bigger than a Point, and under no ſenſible Angle: But the *Moon* when it is in the Horizon has a ſenſible *Parallax*, and ſometimes it is greater than a Degree.

Plate XII. Fig. 2.

HENCE it follows, that the *Parallax* always ſhews the *Moon* more depreſſed, or at greater Diſtance from our *Vertex* than it really is: This Depreſſion will change its place according to the Ecliptick, and make the *Moon* appear to have a Longitude and Latitude different from what it has when ſeen from the Center of the *Earth*. For in the Figure, let the Circle HCZ be the Meridian, or the Circle paſſing through the *Vertex* of the *Spectator* and the *Pole*; let Z be the *Vertex*, HED the *Horizon* of the place, CE the Ecliptick, in which let the *Moon* according to its true place be in L, without any Latitude; let ZT be a Vertical Circle paſſing through the *Moon*; and becauſe the *Parallax* always depreſſes the *Moon* in the Vertical, the apparent place of the *Moon* will be further diſtant from the *Vertex* Z than the true place is. Let the apparent place be O, and ſince the true place is L, the *Parallax* will be LO; which being in the Vertical or Circle of Altitude, is called the *Parallax* of Altitude. Through O let there a Circle paſs which is perpendicular to the Ecliptick, meeting with the Ecliptick in *m*, that Point will be the apparent place reduced to the

Ecliptick, and the Arch L m is called the *Parallax of Longitude*, and O m the viſible Diſtance of the *Moon* from the Ecliptick, is called the *Moon's Parallax of Latitude*. For determining the *Phaſes* of Eclipſes, as they are to be ſeen from a given place, it is neceſſary to know at that time the true places of the *Moon* and *Sun*, which may be computed by Aſtronomical Tables for any given Moment of Time. Moreover, we muſt know the apparent place of the *Moon*, which is to be determined from the true place, by a Computation of the *Moon*'s *Parallax*; which being premiſed, the Times and *Phaſes* are thus found out.

Plate XII. Fig. 3.

A Calculation of the viſible Eclipſe.

LET $p\,k$ be a Portion of the Ecliptick, S the place of the *Sun* therein, at the time of the true *Conjunction*; and l the apparent place of the *Moon* reduced to the Ecliptick; $l\,o$ the viſible Latitude of the *Moon*, and l S will be its viſible Longitude from the *Sun*. At a ſmall portion of time before the true *Conjunction*, find out again the viſible place of the *Moon* in the Ecliptick, which let it be at p, and let $p\,q$ be the *Moon*'s viſible Latitude: Draw $q\,o$ which produce, and let it meet with the Ecliptick in k, and $q\,k$ will be the viſible way of the *Moon* from the *Sun* at the time of the *Conjunction*. In the Triangle $q\,o\,n$, Right-angled at n, we have $o\,n$ the difference of Longitude of the *Moon* from the *Sun* in p and l, and $q\,n$ the difference of Latitude, whereby we can find the Angle $q\,o\,n$, or $q\,k\,p$, which is equal to it, and which is the Inclination of the viſible way of the *Moon* to the Ecliptick: from thence alſo we can find the ſide $q\,o$, and by them we can find the Lines $o\,t$, $t\,k$, S k, and S t. For $p\,l$ is to $q\,o$, as $l\,s$ is to $o\,t$: And in the Triangle $o\,l\,k$, by having $o\,l$ and the Angle k, we can find $o\,k$ and $l\,k$, and thereby $l\,k$, S k, and S t. Now when the Center of the *Moon* is ſeen at t, then is the viſible *Conjunction* of the *Sun* and *Moon*. And therefore we ſay, As $q\,o$ is to $o\,t$, or as $p\,l$ is to l S, ſo is the Time that the *Moon* moves through the ſpace $q\,o$, to the Time it moves through $o\,t$; and then we ſhall have the time between the true and viſible *Conjunction.* From S upon the way of the *Moon* let fall a Perpendicular S *m,* and in the Right-angled Triangle S *k m,* we have S *k* and the Angle *k* ; therefore we can find out S *m,* which is the leaſt viſible diſtance, or the neareſt Approach of both *Sun* and *Moon.* If this diſtance be greater than the Sum of the Semidiameters of the *Sun* and *Moon,* there will be no Eclipſe viſible in that place ; but if it be leſs, the difference reduced into Digits will ſhew the Quantity of the Eclipſe. Having the ſide S *m,* and the Angle *t* S *m,* which is equal to the Angle *k,* we can find out the Line *t m,* and thence the time the *Moon,* in her viſible way, takes to deſcribe the Line *t m,* which is the time between the viſible *Conjunction* and the Moment of greateſt Obſcuration.

Plate XII. Fig. 4.

A Calculation of the Beginning and End of the Eclipſe.

THE Beginning of the Eclipſe is thus determined: Let *p k* be a Portion of the Ecliptick, as before ; S the Center of the *Sun* ; let *q k* be the viſible way of the *Moon,* S *m* its ſhorteſt diſtance from the *Sun.* Draw from the *Sun* to the way of the *Moon* the Right Line *s q* equal to the Semidiameters of both *Sun* and *Moon* : And then when the Center of the *Moon* comes to *q,* the Eclipſe will begin to be viſible, and the two Margins of the *Sun* and *Moon* will ſeem to touch one another. In the Rectangled Triangle *q* S *m,* we have the ſide S *q,* equal to the Sum of the Semidiameters of the *Sun* and *Moon,* and S *m* the neareſt Approach of their Centers ; from whence we can find out the Angle *q* S *m* the Angle of Incidence, and alſo the ſide *q m* ; and thereby we have the time wherein the *Moon* deſcribes the Line *q m,* and from thence the time between the Beginning of the Eclipſe and the time of the greateſt Obſcuration.

AFTER the ſame Method we may find the time of the viſible End of the Eclipſe. But here we muſt begin again, and compute a-new by the *Parallaxes* the viſible way of the *Moon* from the *Sun,* after the *Conjunction,* which will not be the ſame it was before. For the Inclination of the viſible

viſible way is conſtantly changing, becauſe the Quantity of the *Parallax* is in a perpetual Flux, as the *Moon* riſes and falls in Altitude. Seek therefore, about an Hour after the *Conjunction*, the viſible Longitude of the *Moon* from the *Sun*, and its viſible Latitude, and from them compute the Inclination of the *Moon's* way from the *Sun*; which being found, by the ſame Method we found the time of the Beginning of the Eclipſe, we may likewiſe find the time of its End.

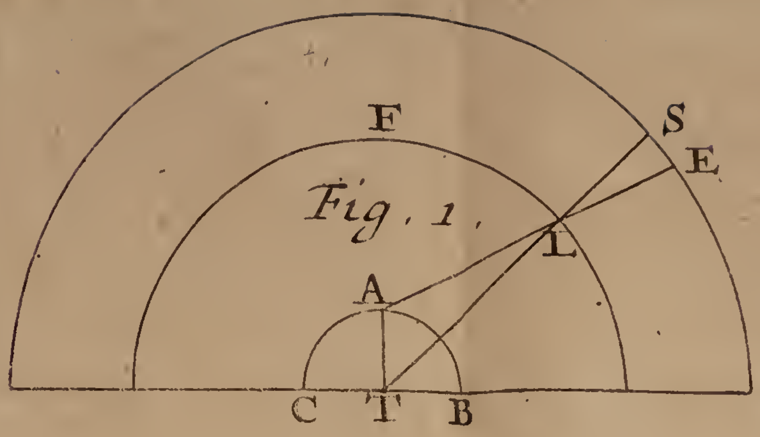
A Determination of the Phaſis *for any Moment of Time.*

IF the *Phaſis* of an Eclipſe for any Moment of time be required, find for that time the place of the *Moon* in her viſible way, and at that Center, and with a diſtance equal to the Semidiameter of the *Moon*, deſcribe a Circle; likewiſe at the Center S, with a diſtance equal to the Semidiameter of the *Sun*, deſcribe another Circle; the Interſections of theſe two Circles will ſhew the *Phaſis* of the Eclipſe, and the Quantity of Obſcuration, as alſo the Poſition of the Cuſps or Horns.

BEFORE we make an end of this Doctrine of Eclipſes, it will be requiſite to explain one notable Appearance, and to ſhew the Reaſon of it.

IN Total Eclipſes of the *Moon*, even when ſhe is near the Center of the Shadow, her Body is frequently to be ſeen of a pale and languid Colour, which could not be without her being illuminated with ſome Light; and ſome will wonder from whence ariſes this Light. Some ſuſpected that it was the native and proper Light of the *Moon* her ſelf. Others derived it from the *Planets* and *Stars*; for the Interpoſition of the *Earth* intercepts all the Light of the *Sun*, and ſeems to bring a thick Darkneſs upon the whole ſpace taken up by the Conical Shadow. But we muſt conſider that the *Earth* is ſurrounded with a Sphere of Air of a conſiderable Depth and Denſity, which has a refractive Power, whereby it turns the Rays of the *Sun* out of their way when they fall upon it, and makes them enter the Conical Shadow; which therefore will be illuminated by that ſmall Quan-

Plate XII *fronting . p . 155.*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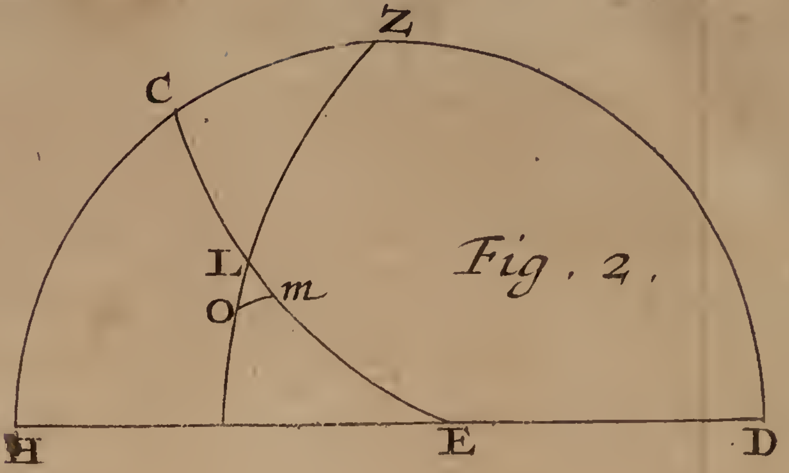
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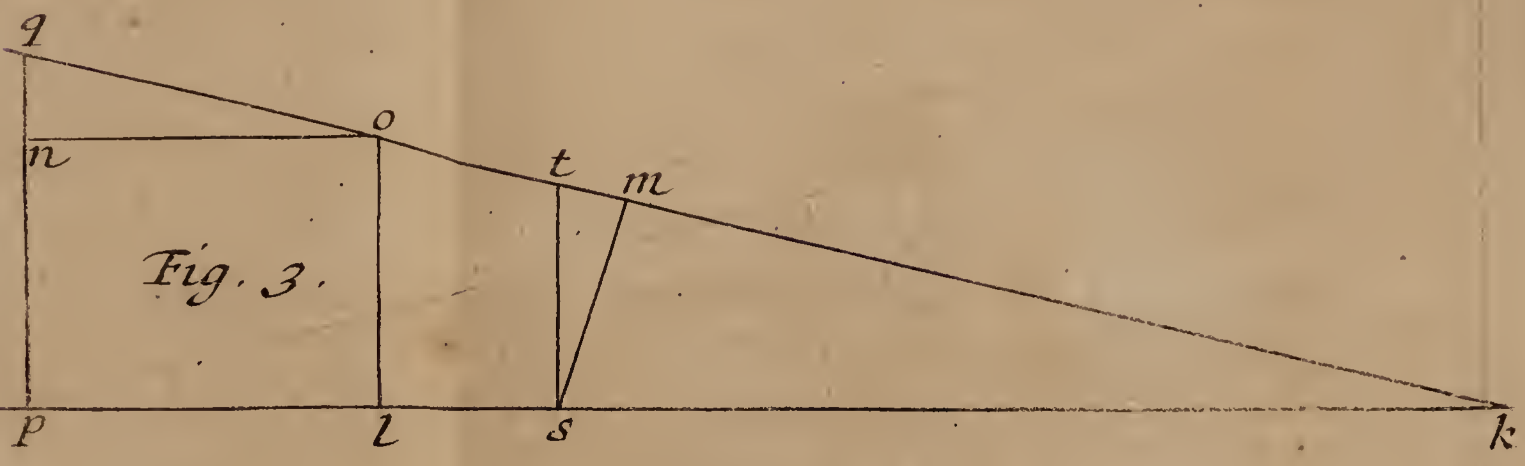
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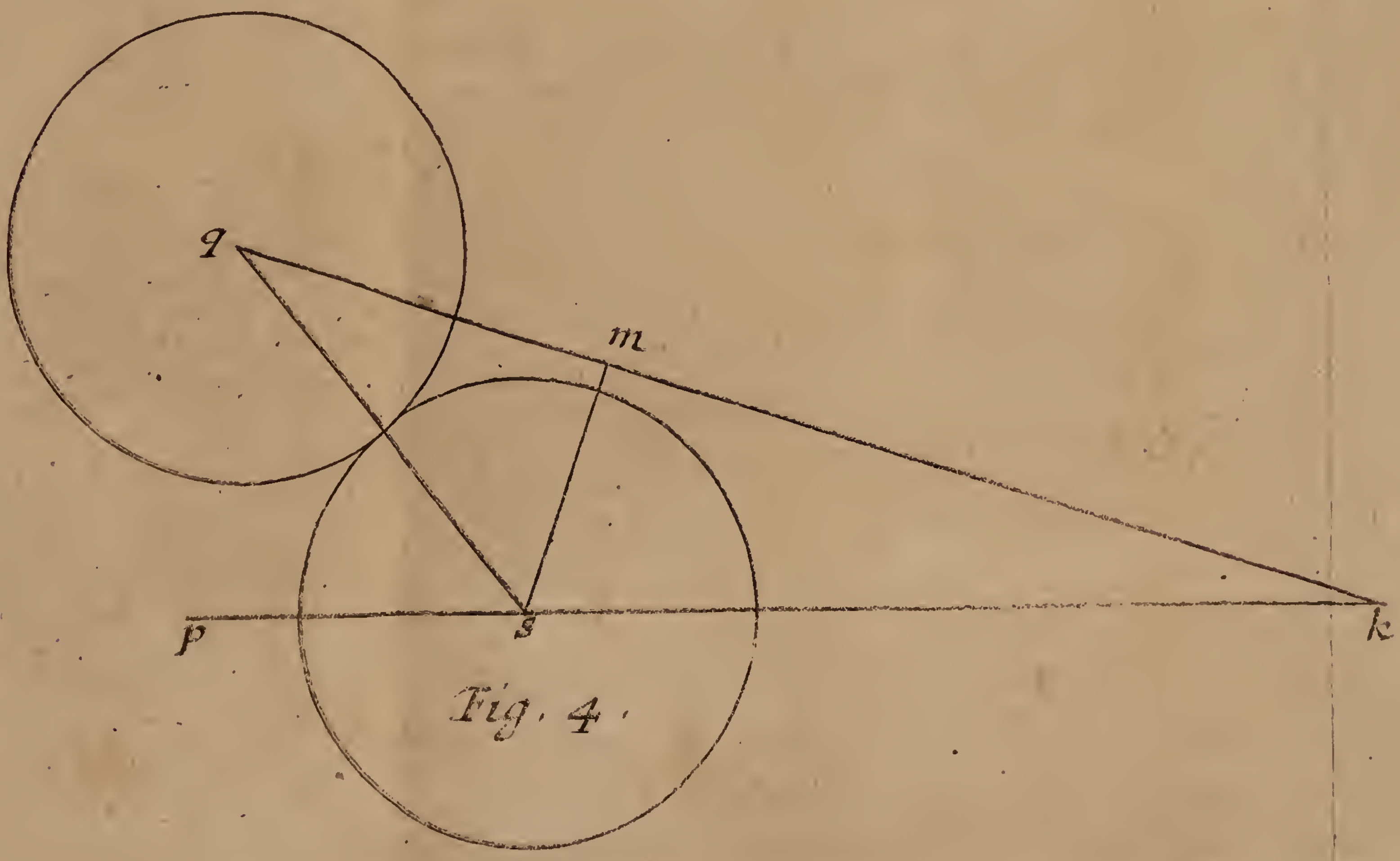
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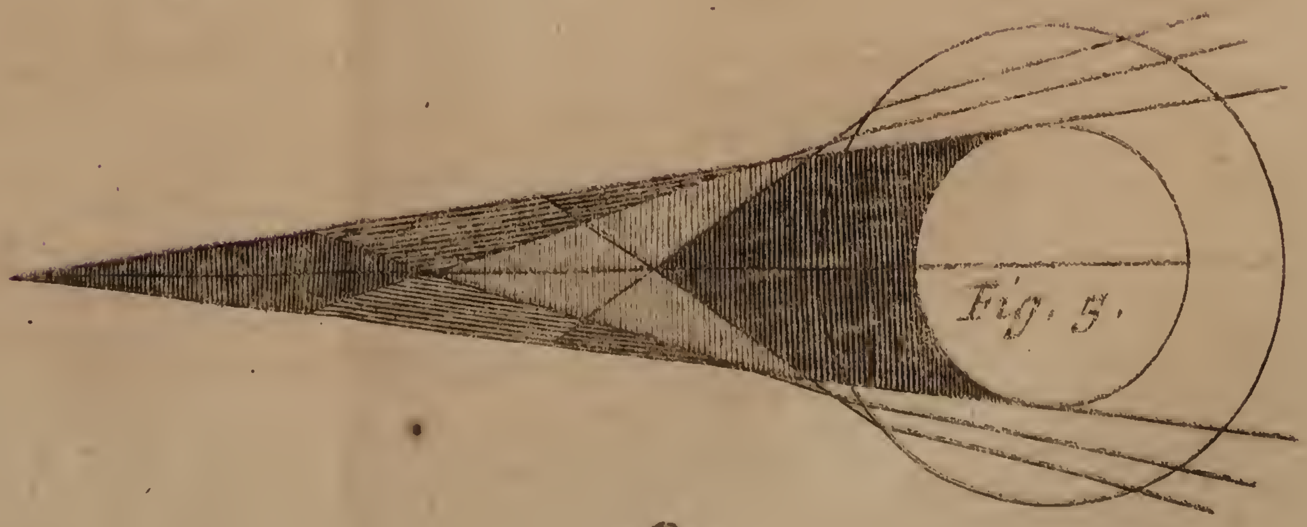


Fig. 5.

tity of Light which falls obliquely on our Atmoſphere, and imparts to all the Bodies within it a faint Light, the which will illuminate the *Moon*, even when it is in the midſt of the Shadow, and make it viſible to our Eyes, as the Figure ſhews.

Plate XII. Fig. 5.

LECTURE XV.

Of the Phænomena *or Appearances ariſing from the Motions of the* Earth, *and the two inferiour Planets* Venus *and* Mercury.

HITHERTO we have contemplated the Motions of the *Earth* and *Moon*, and have given an Account of many Appearances that ariſe from them. The *Moon* indeed is no primary *Planet*, but a ſecondary, which does no other ways go round the *Sun* the true Center of our Syſtem, than by accompanying our *Earth* to whom ſhe properly belongs, in her annual Courſe round the *Sun*.

The ſix Primary Planets.

BUT the Chief and Primary *Planets* of our Syſtem, which perform their Circulations round the *Sun*, without regarding any other Body, are in Number ſix, *viz.* *Mercury* ☿, *Venus* ♀, the *Earth* ♁, *Mars* ♂, *Jupiter* ♃, and *Saturn* ♄, whoſe Motions and Appearances are now to be explained. And, *firſt*, we have already demonſtrated, that the Orbits of *Venus* and *Mercury* include the *Sun*, and that they are included within the Orbit of the *Earth*; and ſince they finiſh their Circulations in leſs time than the *Earth* does, it is manifeſt that theſe *Planets* ſeen from the *Sun*, will appear in the Heavens ſometimes nearer, and ſometimes further from the *Earth*; and that ſometimes they may from thence appear in the ſame Point, and ſometimes in oppoſite Points of the Heavens, with the *Earth*. And becauſe *Venus* and *Mercury* are carried faſter about than the *Earth*, a *Spectator* in the *Sun*, after ſeeing either of them in *Conjunction* with the *Earth*, will ſee it recede from the *Earth*, which follows with a ſlower Motion, and get by degrees a good way to the *Eaſt* of the *Sun*.

AS theſe *Planets*, ſeen from the *Sun*, change their Poſitions in reſpect to the *Earth*, ſo likewiſe we ſeeing them from the *Earth*, obſerve that they change their Poſitions in reſpect to the *Sun*, and are ſometimes nearer, ſometimes further removed from him; and ſometimes they appear in *Conjunction* with the *Sun*. But the *Conjunctions* of theſe *Planets* ſeen from the *Earth*, do not only happen when the *Earth* and they are ſeen together in *Conjunction* from the *Sun*, but alſo when a *Spectator* in the *Sun* ſees the *Earth* and them in Oppoſition: even then the *Sun* and they ſeen from the *Earth*, appear to be in *Conjunction*. For let S be the *Sun*, ABC the Orbit of the *Earth*, FHV the Orbit of *Venus*; and let the *Earth* be in T and *Venus* in V, in the Line which joins the Centers of the *Earth* and *Sun*: In this Poſition *Venus* ſeen out of the *Sun* is in *Conjunction* with the *Earth*, as the *Sun* from the *Earth* is ſeen conjoined with *Venus*.

Two Caſes of Conjunctions.

Plate XIII. Fig. 1.

BUT if the *Earth* were in T, and *Venus* in F, a *Spectator* in the *Sun* will ſee *Venus* and the *Earth* in Oppoſition, or in oppoſite Points of the Heavens. But a *Spectator* in the *Earth* will ſee *Venus* not in Oppoſition to the *Sun*, but in *Conjunction* with him. In the firſt Caſe of theſe *Conjunctions* *Venus* is between the *Sun* and the *Earth*; in the other the *Sun* is ſituated between the *Earth* and *Venus*; and *Venus* goes above the *Sun*: the firſt is called the *inferiour Conjunction*, the ſecond the *ſuperiour*.

AFTER either of theſe two ſorts of *Conjunctions*, *Venus* will ſeem daily to remove further from the Neighbourhood of the *Sun*, and will daily ſeem to get further off from him; but ſtill ſhe keeps within certain Bounds, for ſhe never comes to be oppoſite to the *Sun*; nor does ſhe even arrive at *Quadrantile Aſpect*, which is 90 Degrees, or a *Sextile Aſpect*, which is 60 Degrees diſtant from the *Sun*. And *Venus* is ſeen at her greateſt diſtance from the *Sun*, when the Line which joins her Center with the *Earth* touches the Orb of *Venus*, as about D. For when this *Planet* is further advanced to H, its place in the Heavens is ſeen to be nearer to the *Sun* than it was before at D. Now before ſhe came to D, ſhe always receded more and more from the *Sun*. And after ſhe has left D, ſhe every Day comes nearer to the *Sun*: It is neceſſary, that between the times of her Receſs and Approach, ſhe become ſtationary in reſpect to the *Sun*, and for ſome time appear to keep the ſame diſtance from him; at which time the viſible Motion of *Venus* will be equal to that of the *Sun*. The Arch of a great Circle intercepted between *Venus* and the *Sun*, is called the *Elongation* of that *Planet* from the *Sun*.

The Elongation of a Planet *from the* Sun.

BUT here it is to be obſerved, that only in a Circle, which has the *Sun* for its Center, the greateſt Elongation happens, when the Right Line which joins the *Earth* and *Planet* touches. For in an Elliptick Orbit it may be, that the Elongation from the *Sun* may grow ſtill greater, even after it has left the place where the Line joining the *Earth* and *Planet* touches its Orbit. For after that, the true diſtance of the *Planet* from the *Sun* may increaſe, whilſt the diſtance of the *Sun* nd *Planet* from the *Earth* does not increaſe, but ey may rather decreaſe. And therefore in two Triangles the greater Baſe will ſubtend the greater Angle. But becauſe the Orbits of the *Planets* are nearly circular, ſuch ſmall differences may be here neglected.

The Elongation is not always greateſt when it is in a Line touching the Planets *Orbit.*

THE greateſt Elongation of *Venus* is found by Obſervation to be about 48 Degrees, by which in a circular Orbit we may know the diſtance of *Venus* from the *Sun* in reſpect of the *Earth*'s diſtance from the ſame: For S T is to S D, as the *Radius* is to the *Sine* of the Angle S T D, which is the greateſt Elongation.

HENCE alſo it is manifeſt, that *Venus*, from the time of her ſuperiour *Conjunction*, where ſhe is furtheſt from the *Earth*, to the time of her inferiour *Conjunction* with the *Sun*, where ſhe approaches neareſt it, is always ſeen more *Earſterly* than the *Sun*; and all that time *Venus* ſets later than the *Sun*, and is ſeen after Sun-ſetting; and then ſhe is called the *Evening-Star* or *Veſperus*, being a Fore-runner of Night and Darkneſs. But from the inferiour *Conjunction*, till ſhe comes again to the ſuperiour, ſhe is always obſerved to be to the *Weſtward* of the *Sun*, and conſequently muſt ſet before him in the Evening, and riſe before him in the Morning, and then ſhe is only to be ſeen before Sun-riſing; when ſhe is called the *Morning-Star* or *Phoſphorus*, her Appearance foretelling that Light and Day are at hand.

LET us now ſuppoſe *Venus* and the *Earth* to be ſeen out of the *Sun* in *Conjunction*, and the one to be at V, the other in T, in the ſame Point of the Ecliptick: In which Poſition *Venus* and the *Sun* are ſeen from the *Earth* likewiſe in *Conjunction*. After this, *Venus* circulating faſter than the *Earth*, being come again to V, and having finiſhed her Courſe, and by an angular Motion round the *Sun* deſcribed four Right-angles, will not have overtaken the *Earth*; who in the mean time has proceeded further in her proper Orbit. And therefore *Venus* muſt ſtill move further on to come in a Right Line between the *Sun* and the *Earth*. Let S L M be the next Right Line in which *Venus* is ſeen from the *Sun* together with the *Earth*, ſo that *Venus* may be in L when the *Earth* is in M: now before *Venus* can overtake the *Earth*, ſhe muſt not only finiſh her whole Circula-

The time between two Conjunctions *of the ſame kind.*

tion or four Right-angles, but alſo ſo much angular Motion more as the *Earth* has made in the mean time round the *Sun.* Now the angular Motions of *Venus* and the *Earth* performed in the ſame time, are reciprocally as the Periodical Times of *Venus* and the *Earth.* And therefore as the Periodical Time of the *Earth* is to the Periodical Time of *Venus,* ſo is the angular Motion of *Venus* (which is equal to four Right Angles, and moreover to the angular Motion the *Earth* makes from the time of one *Conjunction* to the next) to the angular Motion of the *Earth.* And therefore by Diviſion of Proportion, As the Difference between the Periodical Times of the *Earth* and *Venus* is to the Periodical Time of *Venus,* ſo are four Right Angles to a fourth Quantity; which ſhews the angular Motion of the *Earth* from the time of her *Conjunction* with *Venus,* to the time of the next *Conjunction* of the ſame kind. Now the Periodical Time of the *Earth* is 365 Days and 6 Hours, or 8766 Hours. And the Period of *Venus* conſiſts of 224 Days 16 Hours, or 5392 Hours, whoſe Difference is 3374 Hours. Say then, As 3374 is to 5392, ſo are four Right Angles or 360 Degrees, to a fourth Number of Degrees, which is 575; which Motion is equal to a Circulation and a half, and beſides to 35 Degrees; which angular Motion the *Earth* makes in the ſpace of one Year and 218 Days. And therefore if *Venus* ſhould be this Day in *Conjunction* with the *Sun* in the inferiour part of her Orbit, ſhe will not come to the ſame *Conjunction* again till after a Year and ſeven Months and twelve Days. And if one *Conjunction* be in the beginning of *Aries,* the next will fall out when the *Sun* is in *Scorpio.* There is the ſame diſtance of time between any two other ſimilar Poſitions of *Venus* and the *Sun.* For Example, between two ſuperiour *Conjunctions,* or between two ſuch Situations of *Venus,* where ſhe has a given Elongation from the *Sun* the ſame way.

THIS

Another way of doing the ſame.

THIS *Problem* and another of the ſame Nature about the *Conjunctions* of the *Sun* and *Moon*, are otherwiſe ſolved by the *Aſtronomers*; for they find out the Diurnal Motion of *Venus* ſeen from the *Sun*, and likewiſe the Diurnal angular Motion of the *Earth*; and the difference of theſe Motions is the relative Diurnal Motion of *Venus* from the *Earth*, or the Quantity by which *Venus* is ſeen to recede from the *Earth* every Day by a *Spectator* in the *Sun*. Thus the middle Motion of the *Earth* is every Day about 59 Minutes and 8 Seconds: *Venus*'s middle Motion in a Day, is 1 Degree 36 Minutes and 8 Seconds, whoſe difference is 37 Minutes. Say therefore, As 37 Minutes is to 360 Degrees, or to 21600 Minutes, ſo is one Day to that ſpace of time, wherein *Venus* having left the *Earth*, has receded from her 360 Degrees; that is, to the time in which ſhe returns to the *Earth* again, which is the time between two *Conjunctions* of the ſame kind, which will be found to conſiſt of 583 Days.

BUT theſe *Conjunctions* are here computed according to the middle Motions of the *Planets*, ſuppoſing them to move always equably, or with the ſame angular Velocity; and they are therefore called *mean Conjunctions*. But becauſe *Venus* and the *Earth* are really carried in Elliptick Orbits, in which their Motions are conſtantly variable, ſometimes going faſter, and ſometimes ſlower; it may be, that the true *Conjunctions* ſhall happen ſome few Days ſooner or later than the Computation we have given; yet having the time of the *Mean Conjunction*, the true *Conjunction* is from thence to be computed after this manner: Let ABC be the Ecliptick, in which A is the Point where the *Planets* are to be in *Conjunction* according to the mean Motion. For the time of this *Conjunction* compute by Aſtronomical Tables the true Places of the *Earth* and *Venus* in the Ecliptick; and ſuppoſe *Venus*'s true place in the Ecliptick to be D, and the *Earth* in T, by which we ſhall find the diſtance of the *Earth* and *Venus* ſeen

Plate XIII. Fig. 2.

ſeen from the *Sun*: But we have, for that time, the Angular Motions of theſe two *Planets* for any given ſpace of time; for Example, for ſix Hours; and the difference of theſe two Motions will give the Acceſs of *Venus* to the *Earth*, or her Receſs from it in ſix Hours. Say then, As this difference of Motions is to D T, ſo is ſix Hours to the time between the Mean *Conjunction* and the true; which time added to, or ſubſtracted from the time of Mean *Conjunction*, as *Venus* is to the *Eaſt* or *Weſt* of the *Earth*, ſhews the time of their true *Conjunction*.

Venus *conſtantly changes her diſtance from the* Earth.

IT is plain from the Inſpection of the Figure, that though *Venus* does nearly always keep the ſame diſtance from the *Sun*, yet ſhe is continually changing her diſtance from the *Earth*; and her diſtance is greateſt, when ſhe is ſeen in her ſuperiour *Conjunction* with the *Sun*; and it is the leaſt when ſhe is in her inferiour *Conjunction*: And the difference is ſo great, that it equals the whole Diameter of *Venus*'s Orbit; ſo that the diſtance of *Venus* from the *Earth*, when ſhe is in her ſuperiour *Conjunction*, is to her diſtance from the *Earth* in the inferiour, as 1 to 6: And therefore *Venus* approaches the *Earth* ſix times nearer in the one Poſition than in the other; and juſt ſo much are the apparent Diameters of *Venus* changed, as we obſerve them to be. But theſe greateſt and leaſt diſtances are ſomewhat changeable upon the Account of the Elliptical or Excentrick Orbits: For *Venus* is then moſt remote from the *Earth*, where the ſuperiour *Conjunction* happens when *Venus* and the *Earth* are both in their *Aphelions*. And the diſtance of *Venus* and the *Earth* is the leaſt of all, when the inferiour *Conjunction* falls out when *Venus* is in her *Aphelion* and the *Earth* in her *Perihelion*.

The Phaſes *of* Venus *like thoſe of the* Moon.

BECAUSE *Venus* is an opake Globe without any Light of her own, and only ſhines with the borrowed Light of the *Sun*, that Face of *Venus* will only appear bright, which is turned towards

wards the *Sun*, while the oppoſite remains in Darkneſs; and for want of Light, is altogether inviſible. Wherefore if the Situation of the *Earth* be ſuch, that this dark ſide of *Venus* be turned toward the *Earth*, *Venus* will become inviſible, except by chance ſhe appear like a black Spot in the Disk of the *Sun*: But if the whole illuminated Face of *Venus* be turned towards the *Earth*, as it is when ſhe is near her ſuperiour *Conjunction*, then ſhe appears like a full ſhining Orb: and according to the different Poſitions of the *Earth*, *Venus* and the *Sun*; *Venus* will have different Forms, and appear with different Faces and Figures, and will undergo the ſame Changes and Viciſſitudes in her Appearances that the *Moon* does.

Plate XIII. Fig. 3.

LET ABCDEFGH be the Orbit of *Venus*, TL a Portion of the Orbit of the *Earth*, in which the *Earth* is at T, and let *Venus* be in A in her ſuperiour *Conjunction* with the *Sun*; it is manifeſt in this Situation of theſe two *Planets*, that the Face of *Venus* which is illuminated by the *Sun*, is likewiſe turned towards the *Earth*; and then *Venus* will appear to us like a full, lucid Circle, as the *Moon* does at Full: But when ſhe has gone from thence to the Poſition B, ſome part of her obſcure Hemiſphere will be turned towards the *Earth*, and will loſe ſomething of her Fulneſs, and ſeem to us to be gibboſe. When *Venus* comes to the Poſition C, but half her illuminated ſide is turned towards the *Earth*, and then ſhe is ſeen like a half Circle, as the *Moon* is when ſhe enters in her firſt or laſt Quarter. But *Venus*, when ſhe arrives at the Poſition D, has but a ſmall part of her illuminated ſide turned towards the *Earth*: And becauſe ſhe is of a ſpherical Figure, which to us, becauſe of its great diſtance, appears like a Plane; the illuminated part which we ſee will appear to end in Points or Horns, whoſe Direction is always oppoſite to the *Sun*. But *Venus*, when ſhe is in the Poſition E, that is, in her inferiour *Conjunction* with the *Sun*, has her dark ſide totally turned towards the *Earth*, and then ſhe quite diſappears, unleſs ſhe happen to be in her *Node*, or near it; then ſhe will appear like a black Spot to paſs over the Body of the *Sun*; which delightful Spectacle was never ſeen by mortal Eyes but once; and it was our Countreyman Mr. *Horrox*, who alone enjoy'd that Pleaſure. *Venus* will undergo the ſame *Phaſes* while ſhe paſſes through F, G to H. *viz*. about F ſhe is horned, in G a half Circle, in H gibboſe, and in A again full.

THESE Appearances of *Venus*, though they are not to be diſcerned by the naked Eye, yet they are diſtinctly and plainly to be perceived with a Teleſcope. Before the Invention of this noble Inſtrument, when *Copernicus* firſt revived the ancient *Pythagorean Syſtem*, and propoſed it to the Learned in *Aſtronomy*, to whom he maintained, that the *Planets*, among which he reckon'd the *Earth*, did move round the *Sun*, which was immoveable in the Center; it was objected to him, That if the Motions of the *Planets* were ſuch as he ſuppoſed them to be, that then *Venus* ought to undergo the ſame Changes and *Phaſes* as the *Moon* does. *Copernicus* anſwer'd, That perhaps the *Aſtronomers* in after-Ages would find, that *Venus* does really undergo all theſe Changes. This Prophecy of *Copernicus* was firſt fulfilled by that great *Italian* Philoſopher *Galileus*, who directing his Teleſcope to *Venus*, obſerved her Appearances to emulate the *Moon*, as *Copernicus* had foretold: And theſe Obſervations did ſurprizingly confirm the old Syſtem revived by *Copernicus*.

The Prophecy of Copernicus.

Theſe Phaſes *firſt obſerved by* Galileus.

IF the Centers of the *Sun* at S, *Earth* at T, and one of the inferiour *Planets* at O be joined with Lines, they will form the Triangle TSO: And if through the Center of the *Planet* there paſſes two Planes, one perpendicular to the Line TO, and the other to the Line SO; the one will cut off the Hemiſphere which is turned towards the *Earth*; the other, that which is turned towards the *Sun*, and by him illuminated. And the exteriour Angle of the Triangle TSO, which is at the *Planet*; that is, the Angle POS, will be equal to the

Plate XIII. Fig. 4.

The Quantity of Illuſtration.

the Angle *m* O *q*, which meaſures *m q* the Portion of the illuminated Semicircle that is turned towards the *Earth*. For the Angle S O *r* is a Right Angle, and ſo is the Angle *m* O T, which are therefore equal; but the Angles *r* O P and *p* O *q* are likewiſe equal, being vertical to each other; and therefore taking away Equals from Equals, there will remain the Angle S O P, equal to the Angle *m* O *q*; which Angle is meaſured by the Arch *m q*. And therefore the part of the illuſtrated Semicircle which is towards the *Earth*, and is to be ſeen from thence, does always meaſure the exteriour Angle S O P of the Triangle S O T. Now this Arch as ſeen from the *Earth* is projected into its own Verſed Sine upon the Disk, as we ſhewed before in the *Moon*. And hence the Illumination of *Venus* ſeen from the *Earth*, is to her full and total Illumination, all other things remaining the ſame, as the Verſed Sine of the exteriour Angle at *Venus* is to the Diameter of the Circle.

ALTHOUGH *Venus* in A ſhines upon the *Earth* at T with a full Face or Orb, yet ſhe does not appear there with her greateſt Brightneſs and Luſtre; for her Splendor is diminiſhed on the account of her greater diſtance from the *Earth*; and it is leſſened in a greater Proportion than the conſpicuous part of the illuminated Disk is encreaſed. For the Luſtre of *Venus* decreaſes in the duplicate Proportion of the diſtance increaſed. But the viſible illuminated part of her Face encreaſes only according to the verſed Sine of the Angle S O P; and therefore the great Brightneſs of *Venus* is not when ſhe is in A, but rather when ſhe is about O. For ſuppoſe *Venus* at O four times nearer the *Earth* than when ſhe is in A; in that caſe every determined part of the illuminated Disk will give ſixteen times more Light than the ſame part does at A: but in O it may happen that only a fourth part of the illuminated Disk can be ſeen from the *Earth*; and therefore the Brightneſs of *Venus* is more encreaſed by her diſtance being diminiſhed, than the ſame Brightneſs is leſſened on account of a ſmaller Portion of her illuminated Disk being viſible from the *Earth.*

Where the Illuſtration is greateſt.

IF you deſire to know in what Poſition *Venus* appears with the greateſt Luſtre, the great *Geometer* and *Aſtronomer*, Dr. *Edmund Halley* my Collegue, has given us an elegant Solution of this *Problem* in the *Philoſophical Tranſactions*, Numb. 349. wherein he has ſhewn that *Venus* is brighteſt when ſhe is about 40 Degrees removed from the *Sun*; and that then but only a fourth part of her lucid Disk is to be ſeen from the *Earth*. And in this Situation *Venus* has been many times ſeen in the Day-time, even in full Sun-ſhine. This Beauty and Brightneſs of *Venus* is very admirable, who having no native Light of her own, and only enjoying the borrowed Light of the *Sun*, ſhould yet break out into ſo great a Luſtre, that the like is not to be obſerved in *Jupiter*, nor even in our *Moon*, when ſhe is in the ſame Elongation from the *Sun*. 'Tis true, the *Moon*'s Light is much greater, upon the account of her apparent Magnitude, than that of *Venus*; yet it is but a dull, and as it were, dead Light, which has nothing in it of that Vigour and Briskneſs that does always accompany the Beams of *Venus*.

The Plane of Venus's *Orbit does not lie in the Eckliptick.*

IF the Plane of the Orbit of *Venus* coincided perfectly with the Plane of the Ecliptick, *Venus* would always ſeem to move in the *Ecliptick*, and no where recede from it. But *Venus*'s Orbit does not lie in the Plane of the Ecliptick, but is in a Plane which is inclined to it, in an Angle of 3 Degrees and 24 Minutes, and cuts the Plane of the Ecliptick in a Line which paſſes through the *Sun*'s Center, that is called the *Line of the Nodes*. And the two Points, where the Orbit of the *Planet* produced cuts the Ecliptick, are named the *Nodes*. And therefore *Venus* is never ſeen, either from the *Sun* or the *Earth*, in the Ecliptick, but when ſhe is in the *Nodes*; in all the other Points of her Orbit ſhe is ſometimes nearer to the Ecliptick, ſometimes further from it; and ſeen from the *Sun*, ſhe makes her greateſt Excurſion when ſhe is 90 Degrees diſtant from both the *Nodes*.

The Line of the Nodes.

Plate XIII. Fig. 5.

LET TAB be a Circle in the Plane of the Ecliptick, L *n* V N the Orbit of *Venus*, cutting the Plane of the Ecliptick in the Line *n* N; we muſt conceive, the one half of this Orbit of *Venus* *n* L N, to be raiſed, or to ſtand above the Plane of the Ecliptick, and the other half *n* V N to fall below that Plane; and when *Venus* is in N or *n*, ſhe is then in the Ecliptick: But when ſhe arrives at P, ſhe is ſeen to deviate from it; but in L, the Arch N L being a Quadrant ſeen from the *Sun*, ſhe appears to recede the furtheſt from the Ecliptick; and this Point L is called the ***Limit***, determining her greateſt Excurſion: for from thence departing, ſhe again approaches the Ecliptick. If from the Place of *Venus*, as in P, we let fall on the Plane of the Ecliptick a Perpendicular P E, and draw S E, the Angle P S E will meaſure the diſtance of *Venus* from the Ecliptick, which is called *Venus*'s *Heliocentrick Latitude*, or ſuch as it is ſeen from the *Sun*. Now this Latitude, having the place of the *Planet* in its Orbit, is thus inveſtigated: Let the Arch N E be a Portion of the Ecliptick, N P a Portion of the *Planet*'s Orbit produced to the Heavens: Let P be the Place of *Venus*, N the *Node*; and let a Circle paſs through the place of the *Planet* perpendicular to the Ecliptick; the Arch P E of this Circle, intercepted between the *Planet* and the Ecliptick, is the diſtance of the *Planet* from the Ecliptick, or the Meaſure of the Angle P S E. Now in the ſpherical Rectangular Triangle P N E, beſides the Right Angle at E, we have the Side N P, the diſtance of the Planet from the *Node*, alſo the Angle N the Inclination of the Plane of the Orbit to the Ecliptick; wherefore by *Trigonometry* we can find out P E, which is the *Heliocentrick Latitude* of the *Planet*. This *Heliocentrick Latitude*, when the *Planet* comes to the ſame Point of its Orbit, is always the ſame and unchangeable: But the *Geocentrick Latitude*, or the diſtance of the Planet from the Ecliptick, as it is ſeen from the *Earth*, even though the *Planet* be in the ſame Point of her

The Heliocentrick Latitude.

The Geocentrick Latitude.

her Orbit, is not conſtantly the ſame, but alters according to the Poſition of the *Earth*, in reſpect to the *Planet*. For let B T A *t* be the Orbit of the *Earth*, *n* P N, as before, the Orbit of the *Planet*, which ſuppoſe to be at P; from which let fall on the Plane of the Ecliptick the Perpendicular P E: in whatever part of her Orbit the *Earth* is, this Line P E will always ſubtend the Angle which meaſures the *Geocentrick Latitude* of the *Planet*. Suppoſe therefore the *Earth* at T, and *Venus* in P, where ſhe comes neareſt to the *Earth*; in which poſition *Venus* is ſeen in her inferiour *Conjunction* with the *Sun*, and her *Geocentrick Latitude* is meaſured by the Angle P T E. But if *Venus* ſhould be in the ſame Situation P, and the *Earth* were at *t*, and from thence *Venus* were obſerved in her ſuperiour *Conjunction* with the *Sun*, where ſhe is at her greateſt diſtance from us, her *Geocentrical Latitude* would be anſwerable to the Angle P*t*E, which is much leſs than the Angle P T E; becauſe the diſtance P *t* is greater than P T. What we have here ſaid of the Latitude of *Venus*, is likewiſe true of that of *Mercury*, and upon the ſame Account. Hence it is plain, that the inferiour *Planets*, all other things remaining the ſame, have a greater Latitude when they are near the *Earth*, than when they are further off. And it may happen that the *Geocentrical Latitude* of *Venus* may be greater than her *Heliocentrick*, which will be when ſhe is between the *Sun* and the *Earth*, and ſhe is nearer to us than to the *Sun*. But *Mercury* keeping always at a greater diſtance from the *Earth* than he has from the *Sun*, his *Geocentrick Latitude* will conſtantly be leſs than his *Heliocentrick*, which when at the biggeſt is about 7 Degrees; for ſo much is the Inclination of his Orbit to the Plane of the Ecliptick.

Plate XIII. Fig. 6.

SINCE none of the Orbits of the *Planets* lie in the Plane of the Ecliptick, but all of them cut it in a Line paſſing through the *Sun*, no *Planet* can be above twice in the time of its Period in the Ecliptick, which is when they are in their

Nodes; at all other times every one of them will deviate ſome more, ſome leſs, from the ſaid Plane of the Ecliptick: But yet there are certain determinate Boundaries which they never tranſgreſs. And therefore if we imagine in the Heavens a Zone, or broad Circle of 20 Degrees breadth, that is, 10 Degrees on each ſide of the Ecliptick which lies exactly in the middle of this Space or Zone; ſuch a Space will conſtantly contain all the *Planets* in its Compaſs, and is called the *Zodiack*, from the Images of living Creatures, or the Conſtellations which fill that part of the Heavens: The *Earth* keeping always, as it were, in the King's Highway, never turns out from its Courſe in the Ecliptick, but the *Moon*, and the other five Wanderers will make Excurſions from it, for ſeveral Degrees, ſometimes to the *North-ſide*, and ſometimes to the *South-ſide* of the Ecliptick; and yet they always keep within the Bounds of the *Zodiack*.

The Zodiack.

The Motion of Venus *in the* Zodiack.

HITHERTO we have conſidered the Motions and *Phaſes* of *Venus*, as they have a Relation to the *Sun* and *Earth*: let us next conſider the Motions of *Venus* in the Heavens, as they are obſerved from the *Earth*, and the Way ſhe takes in the *Zodiack*. For which purpoſe let A B C be the Orbit of *Venus*, T G F the Orbit of the *Earth*, the Circle L M O the *Zodiack* among the *fixed Stars*: and, firſt, ſuppoſe the *Earth* in T, and *Venus* in A, near her ſuperiour *Conjunction* with the *Sun*; it is evident, that a *Spectator* on the *Earth*, will ſee *Venus* at A, as if ſhe were in the Point of the *Zodiack* L: if the *Earth* had no Motion while *Venus* moves from A to B in its Orbit, it would ſeem to deſcribe the Portion of the *Zodiack* L M: But in the mean time the *Earth* alſo moves; and when *Venus* is in B, the *Earth* is come to the Point of its Orbit H; from whence the *Spectator* looking upon *Venus* at B, obſerves her in the *Zodiack* at N; ſo that ſhe will ſeem to have run through the Space L M N in the *Zodiack*: and *Venus* will appear to have gone more *Eaſtward* than

Plate XIII. Fig. 7.

than ſhe would have done, had the *Earth* ſtood ſtill without any Motion in its Orbit. But when *Venus* comes to C, the *Earth* has moved on to G; ſo that *Venus* is ſeen in the Line GO drawn from the *Earth*, which touches her Orbit; in which Poſition her apparent Motion in the *Zodiack* will be very nearly equal to the apparent Motion of the *Sun*: From thence let *Venus* move on from C to A, and in that time the *Earth* will have come from G to K, and then *Venus* will be ſeen near her inferiour *Conjunction* with the *Sun*; in which Poſition ſhe will be obſerved in the *Zodiack*, as if ſhe were at P: but before ſhe was ſeen at O, and therefore ſhe will here appear to have gone backwards in the *Zodiack* through the Arch O P, or to have moved from the *Eaſt* to the *Weſt*, contrary to the Order of the Signs. And becauſe in C ſhe was obſerved to go *Eaſtwards* as faſt as the *Sun* does; but in A ſhe is ſeen to have a quick Motion backward: There muſt be ſome place of her Orbit between C and A, where ſhe appears to us neither to go forward nor backward, but to ſtand ſtill, and continue in the ſame place in the Heavens: In which caſe ſhe is ſaid to be *Stationary*, or to ſtand ſtill.

Venus *Direct.*

Venus *Retrograde.*

Venus *Stationary.*

LET *Venus* now arrive at E, and the *Earth* at the Point of its Orbit F, *Venus* will then be ſeen in the Point of the Ecliptick Q, and will appear to have moved further backwards in the Ecliptick, or towards the *Weſt*. But when *Venus* is ſeen from the *Earth* in a Line which touches her Orbit, ſhe will then ſeem to have a progreſſive Motion, equal to the apparent Motion of the *Sun* from *Weſt* to *Eaſt*: And becauſe before, her apparent Motion was backward, or from *Eaſt* to *Weſt*, and now forward the contrary way, from *Weſt* to *Eaſt*, there muſt be ſome place between the two contrary Motions, where ſhe will neither appear to go backwards nor forward; but for ſome time to ſtand ſtill, and keep the ſame Poſition in the Heavens. While the *Earth* comes to D, and *Venus* arrives at C, ſhe will appear in that time to have moved through the Arch Q R of the *Zodiack*, and to have a quicker Motion towards the *Eaſt*. Hence *Venus*, when ſhe is in her ſuperiour *Conjunction* with the *Sun*, is always ſeen to move directly according to the Order of the Signs; but when ſhe is in her inferiour *Conjunction*, and between the *Earth* and the *Sun*, then ſhe is ſeen to have a backward Motion, and to be carried againſt the Order of the Signs, from *Eaſt* to *Weſt*.

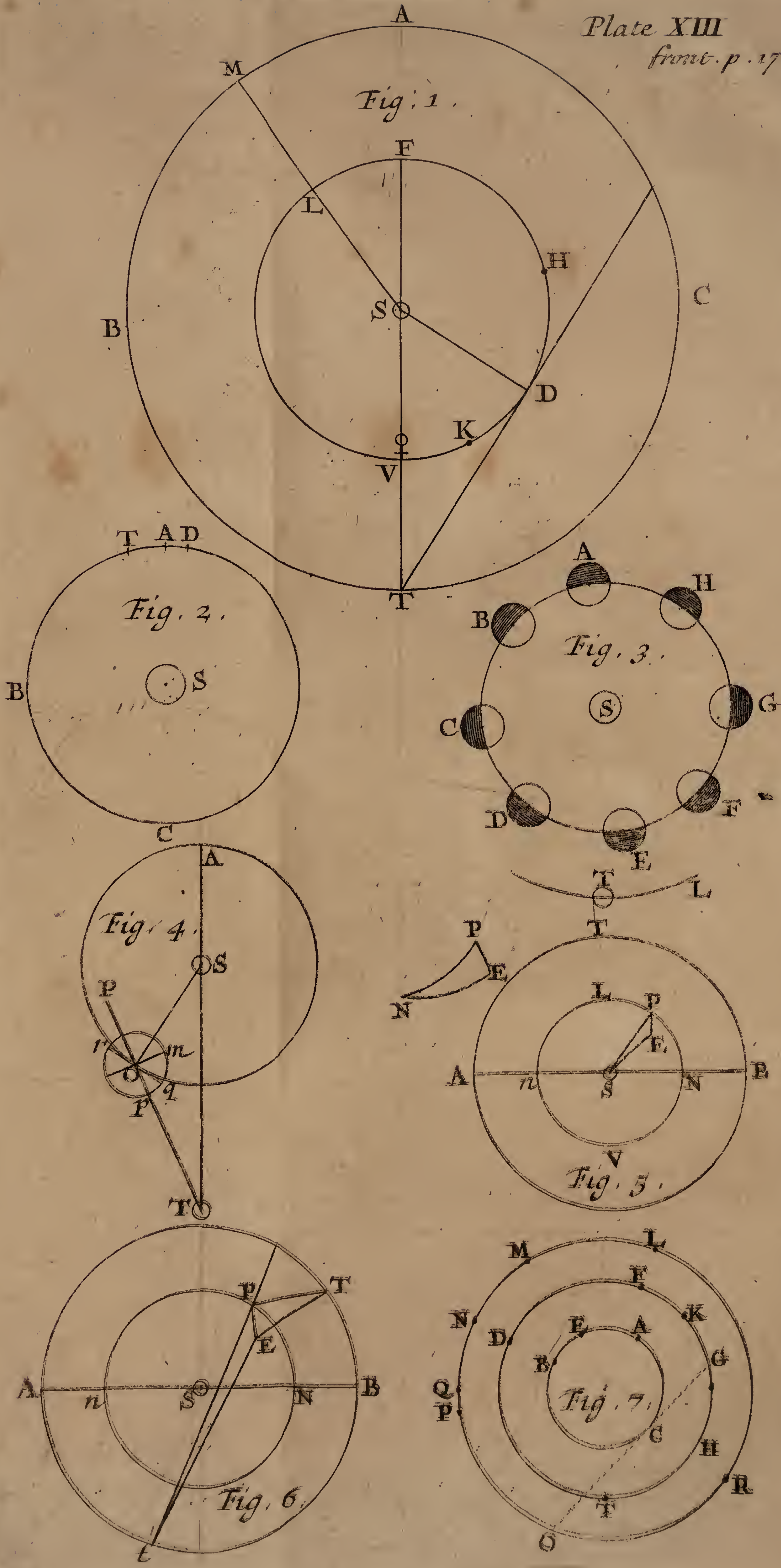
The Appearances of Mercury *like thoſe of* Venus.

WHATEVER we have demonſtrated concerning the Motions of *Venus*, is likewiſe true, and to be underſtood of the Motions of *Mercury*; but the *Conjunctions* of *Mercury* with the *Sun*, his Directions, Stations and Retrogradations, are more frequent than in *Venus*; for *Mercury* circulating faſter, and in a leſſer Orbit than *Venus*, does oftner overtake the *Earth* than ſhe. Hence it is plain, that the Motions of theſe two *Planets* ſeen from the *Earth*, are very irregular and unequal, ſince they are ſometimes ſeen to have a Motion forward; ſometimes they appear immoveable or ſtationary, after this they change their Courſe, and move backwards, and after ſuch a Regreſſion they again take up their Stations, and keep for ſome time the ſame place in the *Zodiack*. Whereas a *Spectator* in the *Sun* will always obſerve theſe *Planets* to go forward with a Motion regulated after a certain Rate. For the apparent Inequality of theſe Motions ſeen from the *Earth*, is ſuch as exactly anſwers to a regular Motion round the *Sun*. And therefore it is manifeſt, that the *Sun*, and not the *Earth*, is the Center of theſe *Planets* Motion.

The Orbits of Mercury *and* Venus *Elliptical.*

WE ſhewed before, that the Orbit of the *Earth* was not a Circle, but an Ellipſe; the ſame thing is true of the Orbits of *Venus* and *Mercury*, and of all the other *Planets*, which are really Ellipſes and not Circles, that have one common *Focus* in which the *Sun* reſides, about whom the *Planets* perform their Circulations with Motions; which though not perfectly equable, yet they are all regulated

Plate XIII
front. p. 170



gulated by a certain, unchangeable and conſtant Law, which none of them tranſgreſs; for every *Planet* moves in the *Perimeter* of his own Ellipſe, ſo that the Line or Ray paſſing from its Center to the Center of the *Sun*, does always deſcribe or ſweep an Elliptick Space or *Area* proportional to the Time; or which is the ſame thing, in equal time it ſweeps an equal *Area*. Hence the *Planets* muſt move more ſlowly in their *Aphelia*, and quicker in their *Perihelia*: And theſe *Aphelia* are not like the *Apogeon* of the *Moon*, but they are either at reſt without Motion, or if they have any, it is ſo ſlow, that it is not eaſily perceived in the time of a Man's Age. And here it is to be obſerved, that of all the *Planets*, *Mercury* has the moſt Excentrick Orbit; for therein the Excentricity is to the mean diſtance as 2051 to 10000.

LECTURE XVI.

Of the Motions of the three ſuperiour Planets, Mars, Jupiter *and* Saturn, *and the Appearances ariſing from them.*

Theſe ſuperiour Planets may have any Poſition or Aſpect in reſpect of the Sun.

Plate XIV. Fig. 1.

WE have now dwelt long enough, on the Explication of the Motions of the two inferiour *Planets*; let us next contemplate the ſuperiours. For which purpoſe let ABCT be the Orbit of the *Earth*, and let *Saturn*, *Jupiter* and *Mars* turn round the *Sun* in different Orbits at their proper diſtances, and perform their Circulations, each in its proper Period; and let PQV be a Portion of the *Zodiack* in which theſe *Planets* are obſerved to perform their Motions. *Firſt*, It is plain, that all theſe *Planets* ſeen from the *Sun*, may be obſerved either in *Conjunction* with the *Earth*, or in *Oppoſition* to it. Thus *Saturn* may be in ♄ when the *Earth* is in M, in the Line which joins the Centers of the *Sun* and *Saturn*; in which Caſe the *Earth* and *Saturn* from the *Sun* are ſeen in *Conjunction*: But the *Earth* may likewiſe be in the ſame Right Line produced the contrary way, as in B, where from the *Sun* theſe two *Planets* will be ſeen in *Oppoſition* to each other. But in this Situation, the *Sun* ſeen from the *Earth*, will appear to be in *Conjunction* with *Saturn*. *Secondly*, It is evident, that theſe *Planets* ſeen from the *Earth*, may have any Aſpect, or obtain any Poſition in reſpect to the *Sun*, and may have any deſired Elongation from him; which cannot be in the inferiour *Planets*, who are always confined to the Neighbourhood of the *Sun*. For from the *Earth* T there may be drawn a Line T P, which will cut all the Orbits of the ſuperiour *Planets*, and may make with T S the Line which joins the *Sun* and *Earth*, any Angle required, as S T P. And therefore when the *Earth* is in T, *Saturn* may be in F, whoſe Elongation from the *Sun* will then be the Angle S T F. Moreover, when the *Earth* and any ſuperiour *Planet* are ſeen from the *Sun* in *Conjunction* together, that *Planet* obſerved from the *Earth*, will appear in *Oppoſition* to the *Sun*; and an Inhabitant of our Terraqueous Globe, will ſee the *Sun* and it, in oppoſite Parts of the Heavens.

The times between two Conjunctions, *or two* Oppoſitions *in the ſuperiour* Planets.

LET now any ſuperiour *Planet*, as for Example, *Saturn*, be ſeen from the *Sun* in *Conjunction* with the *Earth*: After *Conjunction*, the *Earth* having a quicker angular Motion than *Saturn*, an Inhabitant or *Spectator* in the *Sun* will ſee the *Earth* daily to recede more and more from *Saturn*. And becauſe the *Earth*, according to its mean Motion, does every Day deſcribe an Arch of the Ecliptick of 59 Minutes 8 Seconds, and *Saturn* moves only 2 Minutes in a day, the *Earth* will appear from the *Sun* to recede every Day from *Saturn* the ſpace of an Arch of 57 Minutes 8 Seconds. If we ſay then, As 57 Minutes 8 Seconds is to 360 Degrees, or to 21600 Minutes, ſo is one Day to a fourth Quantity; we ſhall have the Number of Days in which the *Earth* will be again obſerved from the *Sun* to be in *Conjunction* with *Saturn*, which is 378 Days. But when the *Earth* and *Saturn* are ſeen from the *Sun* in *Conjunction*, the *Sun* and *Saturn* from the *Earth* appear in *Oppoſition*. And therefore the time between two *Oppoſitions* of the *Sun* and *Saturn*, immediately following one another, computed according to their middle Motions, is 378 Days, or one Year and 13 Days. And there is the ſame time between two *Conjunctions* of *Saturn* and the *Sun* ſeen from the *Earth*, or between any two ſimilar Aſpects or Elongations from the *Sun*. And the time between the *Oppoſition* and *Conjunction* of *Saturn* with the *Sun*, is the half of this time, or 189 Days.

BY the ſame Method we ſhall find, that the time between two *Conjunctions* or *Oppoſitions* of *Jupiter* and the *Sun* conſiſts of 398 Days, or a Year and 33 Days. But *Mars* after an *Oppoſition*, does not again come into the ſame Situation, till after 2 Years and 50 Days.

WHEN the *Planets* are in *Oppoſition* to the *Sun*, they riſe when the *Sun* ſets; and ſet when he riſes; and then after their Departure from the *Oppoſition* to the *Sun*, they remain to the *Eaſtward* of the *Sun*; and after Sun-ſet they are to be ſeen in the Evening, till they come in *Conjunction* with him, when they ſet and riſe together. Afterwards, as they recede from the *Sun*, they become more *Weſterly* than he, and are then only to be ſeen in the Morning before the *Sun* is up; for in the Evening they ſet before the *Sun*, till they at laſt come to be oppoſite to the *Sun*, when again they riſe at Sun-ſet.

The Planes of their Orbits are inclined to the Ecliptick.

AS in the inferiour *Planets*, ſo the ſuperiour have not their Orbits in the Plane of the Ecliptick; for the Planes of all their Orbits cut the Plane of the Ecliptick in Lines which paſs through the

Sun, which are called, the *Lines of the Planets Nodes*: And the Points where theſe Lines meet with the Ecliptick, are called the *Nodes*. And therefore the ſuperiour *Planets* are never preciſely in the Ecliptick, but when they are in the *Nodes*: In all the other Points of their Orbits they are further or nearer to the Ecliptick, according to their Diſtance from the *Nodes*; and their Diſtances are greateſt when they are at equal Diſtances from both *Nodes*; which Points are called the *Limits*, where the greateſt *Heliocentrick* Latitudes which meaſure the Inclinations of the Orbits to the Ecliptick, are as followeth; *Saturn*'s greateſt *Heliocentrick* Latitude is 2 Degrees 30 Minutes. *Jupiter*'s is 1 Degree 20 Minutes, and that of *Mars* is 1 Degree and 52 Minutes.

The Heliocentrick *and* Geocentrick *Latitudes.*

HAVING the Place of a *Planet* in its Orbit, or, which is the ſame thing, its Diſtance from the *Node*, by the ſame Method we find out its *Heliocentrick* Latitude, as we did in the inferiour *Planets Mercury* and *Venus*. But the *Geocentrick* Latitudes, or the Diſtances of the *Planets* from the Ecliptick, as they are ſeen from the *Earth*, depend much upon the Poſition and Diſtance of the *Earth*. For where the *Heliocentrick* Latitude continues the ſame, yet according to the various Poſitions the *Earth* may have, the viſible Latitude of a *Planet* ſeen from thence, will be various. For let T ♂ *t* be the Orbit of the *Earth*; and the Orbit of any ſuperiour *Planet*, as for Example, that of *Mars*, ſuppoſe to be ♂ M, whoſe Plane is inclined to the Ecliptick, and cuts it in the Line of *Nodes n* N. Let *Mars* be in ♂, and the *Earth* in T, ſo as *Mars* may be obſerved in *Oppoſition* to the *Sun*; and from ♂ let fall on the Plane of the Ecliptick the Perpendicular ♂ E; this Line will ſubtend the Angle which meaſures the *Geocentrick* Latitude. And therefore when the *Earth* is in T, the viſible Latitude is meaſured by the Angle ♂ T E. But if the *Earth* was in *t*, ſo that *Mars* was ſeen in *Conjunction* with the *Sun*, its viſible Latitude will be the Arch which meaſures the

Plate XIV. Fig. 2.

Angle ♂ *t* E, which is much leſs than the Angle ♂ T E, and is nearly leſs in the ſame Proportion as the Diſtance T ♂ is leſs than the Diſtance *t* ♂. When the *Earth* is in T, the *Geocentrick* Latitude of *Mars* is greater than its *Heliocentrick*; but when it is in *t*, the *Heliocentrick* is greater than the *Geocentrick*; and according to the various Poſitions of *Mars* and the *Earth*, his viſible Latitude will be changeable; ſo that all other things being alike, the Latitude is greater, the nearer he comes to the *Oppoſition* of the *Sun*, and the leſs, as he approaches to a *Conjunction* with the ſame.

IT is alſo evident, that none of the ſuperiour *Planets* can be ſeen from the *Earth* in the *Sun*'s Disk, as the inferiour *Mercury* and *Venus* are; but yet they may be all of them covered by the *Sun*, and lie hid behind him, when they come in *Conjunction* with him, and are near their *Nodes*.

Jupiter *and* Saturn *have always a round full Face.*

SINCE the Faces of all the *Planets* which are turned towards the *Sun*, ſhine only with a reflected and borrowed Light; and becauſe the *Earth* ſeen from *Jupiter* or *Saturn*, is always to be obſerved near the *Sun*'s Body, the Faces of theſe *Planets*, which are turned towards the *Sun*, will alſo be towards the *Earth*; whence the Inhabitants of our Globe do always behold theſe *Planets* ſhining in full Orbs or Circles. But *Mars* having an Orbit, which lies very near the *Earth*, its Face which is towards the *Sun*, will not always be totally turned towards the *Earth*; but when in his Quadrature, or when there is about a fourth part of the Ecliptick between the *Sun* and him, as ſuppoſe the *Earth* in M or B, and *Mars* in N or R, then ſome part of the illuminated Face will be turned from the *Earth*, and therefore *Mars* will not appear in a compleat Circle, but will be ſeen as deficient or gibboſe; but when he comes to be in *Conjunction* or *Oppoſition*, he then re-aſſumes his round Figure, his illuminated Face being totally turned towards the *Earth*; and particularly when in *Oppoſition* to the *Sun*, he looks brighteſt and biggeſt.

Mars *in his Quadrature, gibboſe.* Plate XIV. Fig. 1.

FOR

In Oppoſition *the ſuperiour* Planets *are biggeſt.*

FOR all the ſuperiour *Planets* appear much bigger when they are in *Oppoſition* to the *Sun*, than when they are in *Conjunction*, being much nearer to the *Earth* in the one Poſition than in the other; inſomuch that the Difference of their Diſtances in theſe two Poſitions, is as great as the Diameter of that Orb in which the *Earth* goes round the *Sun*; which Difference bears a conſiderable Proportion to the Diſtance of *Mars* from the *Sun*, and greater than it does to the Diſtances of the other *Planets*; and therefore will produce a great difference in his apparent Magnitude: For *Mars* is five times nearer to us when he is in *Oppoſition*, than when he is in *Conjunction* with the *Sun*. And therefore ſince the viſible Disk and Luſtre of a *Planet* increaſes in a duplicate Proportion of that wherein the Diſtance is diminiſhed, *Mars* will appear 25 times bigger and brighter when he is in *Oppoſition*, than when he is in *Conjunction* with the *Sun*.

The apparent Diameter of the Sun *ſeen from* Jupiter *and* Saturn.

BECAUSE *Jupiter* is five times further off the *Sun* than the *Earth* is, the apparent Diameter of the *Sun* ſeen from *Jupiter*, will be five times leſs than it is ſeen from the *Earth*, and will be no bigger than 6 Minutes, which to us is 30 Minutes. And the Disk of the *Sun* will appear 25 times leſs to the Inhabitants of *Jupiter*, than it does to us, who will likewiſe receive but the 25th part of the Light and Heat from him that we enjoy. But *Saturn* being 10 times further from the *Sun* than we, the apparent Diameter of the *Sun* ſeen from him, will be no bigger than 3 Minutes, and will be but little more than twice the Diameter of *Venus*, when ſhe approaches neareſt to the *Earth*: And therefore the Disk of the *Sun*, as it would appear to a *Saturnian Aſtronomer*, will be 100 times leſs than we ſee it; and both its Light and Heat are there diminiſhed in the ſame Proportion; and therefore the warmeſt Regions in *Saturn*, even under his Æquator, are much colder than our Frigid Zones.

Their Degrees of Heat compared with our Heat which we receive from the Sun.

Plate XIV
front. p. 176

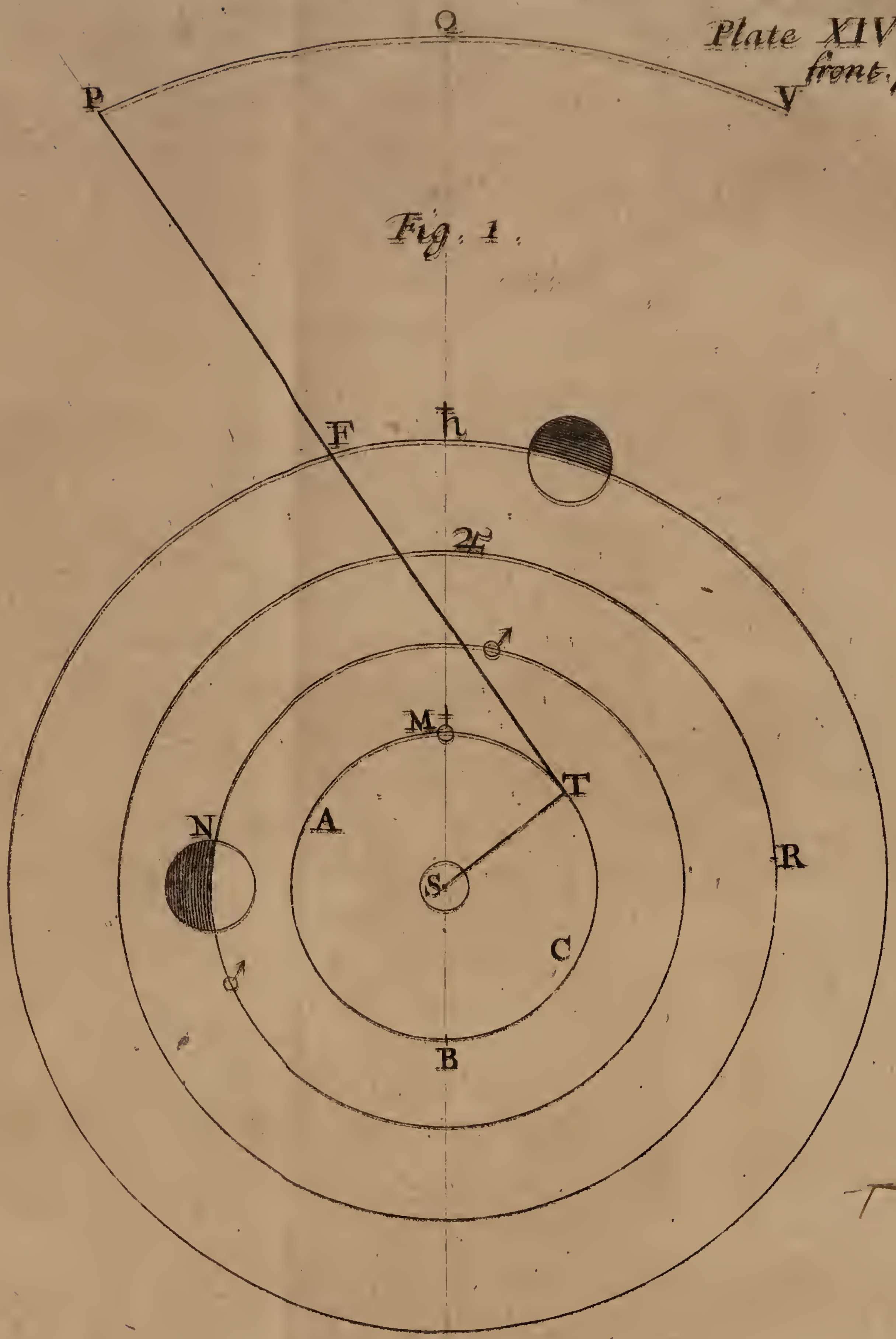


Fig. 1.

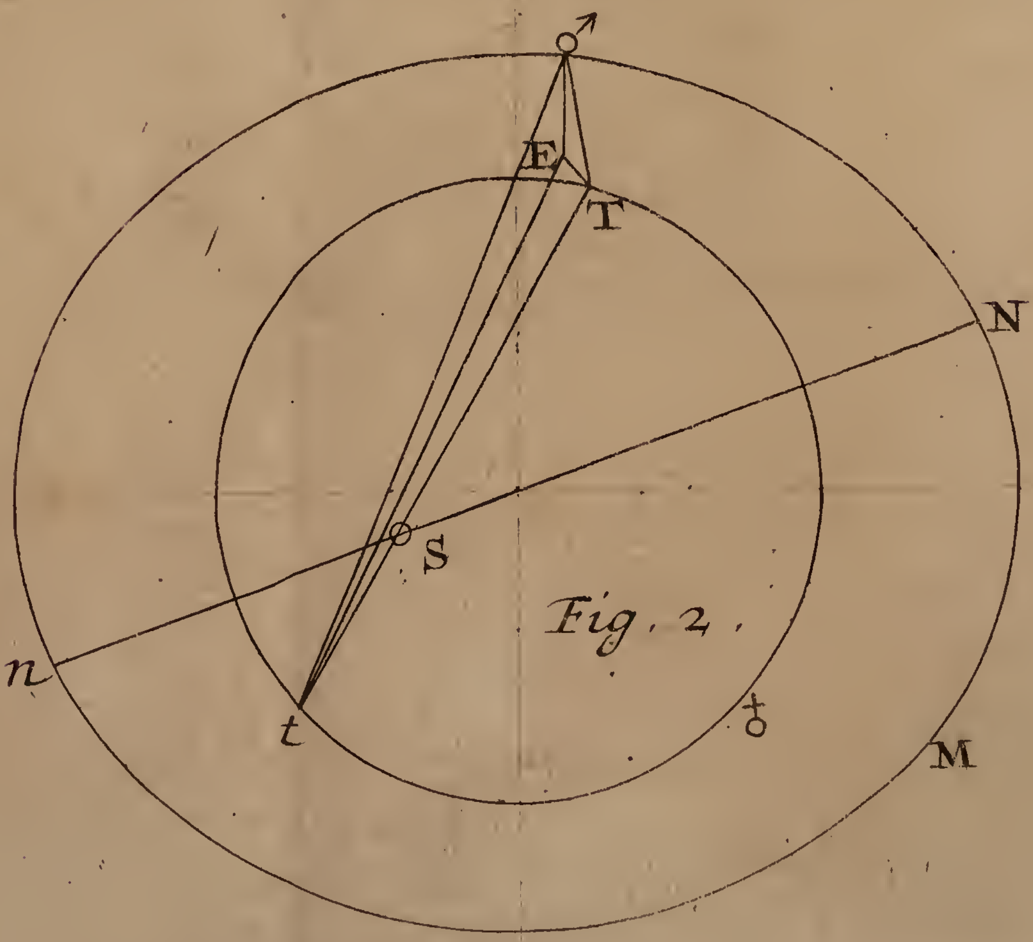


Fig. 2.

ALL the ſuperior *Planets* obſerved from the *Sun*, will appear to move regularly the ſame way, and to proceed in their Orbits according to the ſame Law, which is the equable Deſcription or Sweeping of Elliptick *Area's* round the *Sun*; by which means their angular Motions round the *Sun* will appear ſomewhat unequal; for in their *Aphelia* they proceed more ſlowly; in coming to their *Perihelia* they accelerate their Motions. But theſe *Planets* obſerved from the *Earth*, have very different Appearances, and irregular Motions in the *Zodiack*; ſometimes they ſeem to move forward from *Weſt* to *Eaſt*, according to their real Motions; then they by degrees ſlacken their Pace, till at laſt they loſe all their Motion, and ſeem to ſtand ſtill. After ſome ſmall time they are again ſet a moving, but ſeem to take a contrary courſe to what they had before, and go backwards, directly in Oppoſition to their real and true Motions: And thus having for ſome way gone backward, or from *Eaſt* to *Weſt*, they come again to be immoveable and ſtationary. Theſe great Changes of their Courſes and Motions are not real in the *Planets*, but are occaſioned by the Motion and Poſition of the *Earth*, from whence the *Aſtronomer* obſerves them.

The Motions of the Planets *ſeen from the* Sun, *are very regular.*

But from the Earth *they are obſerved to be very irregular.*

LET PQO be a Portion of the *Zodiack*, ABCD the Orbit of the *Earth*, EMGHZ the Orbit of a ſuperiour *Planet*; for Example, of *Saturn*: and ſuppoſe the *Earth* in A, and *Saturn* in E; in which Poſition he will appear in the *Zodiack* at the Point O. If *Saturn* remained there without any Motion of his own, when the *Earth* comes to B, he would be ſeen in the Point of the *Zodiack* L, and would appear to have deſcribed the Arch of the *Zodiack* OL, and to have moved according to the Order of the Signs, from *Weſt* to *Eaſt*. But becauſe in the mean time, while the *Earth* is paſſing from A to B, *Saturn* does likewiſe move in his own Orbit from E to M, where he is ſeen in *Conjunction* with the *Sun*, he will appear to have deſcribed the Arch of the *Zodiack* OQ;

Plate XV. Fig. 1.

When the ſuperiour Planets *are direct and ſwift.*

which is greater than the Arch O L: whence the ſuperiour *Planets*, when they are in *Conjunction* with the *Sun*, appear to have a Motion forward much quicker than at other times, and that for a twofold Cauſe; which is, becauſe they really have a Motion forward from *Weſt* to *Eaſt*, and likewiſe becauſe the *Earth*, in the oppoſite part of the Heavens, is carried the ſame way round the ſame Center. And therefore theſe *Planets*, when they are at their greateſt Diſtance from us, and in *Conjunction* with the *Sun*, appear to have a quicker Motion than uſual to the *Eaſt*, according to the Order of the Signs: In which Poſition a *Planet* is ſaid to be direct, or to have a direct Motion. When the *Earth* comes to C, while *Saturn* deſcribes the Arch M G, he will then be obſerved in the *Zodiack* at R. But the *Earth* being advanced to K, and *Saturn* to H, ſo as the Line K H joining the *Earth* and *Saturn* continue for ſome time parallel to itſelf, or very nearly ſo; then our *Aſtronomers* will obſerve *Saturn* all that while in the ſame Point of the *Zodiack* at P, and with the ſame *fixed Stars*, he then appearing Stationary. But the *Earth* being come to D, and *Saturn* coming into *Oppoſition* to the *Sun* in X, he will appear in the *Zodiack* at V, and will ſeem to have gone backwards through the Arch P V. And therefore the ſuperiour *Planets*, when they are in *Oppoſition* to the *Sun*, are always Retrograde, or appear to have a backward Motion from *Eaſt* to *Weſt*, which is contrary to the Order of the Signs: But when the *Earth* comes again to A, and *Saturn* remaining near to Z, again that *Planet* will ſeem there to occupy his Station, and to remain without Motion. At laſt, after the *Earth* has left that Situation, *Saturn* will appear to begin again to move forward.

When ſtationary.

What we have here ſhewed concerning *Saturn*, is likewiſe to be underſtood of *Jupiter* and *Mars*, who are likewiſe obſerved to have all theſe Variations and Changes in their Motions, as ſometimes

times to move quickly forwards, then to ſtand ſtill, and after that to fall backward; then again they become ſtationary, and in a ſhort time after they go forward with a direct Motion. But the Regreſſions or backward Motions of *Saturn*, are more frequent than thoſe of *Jupiter*; becauſe the *Earth* more frequently overtakes *Saturn*, whoſe Motion is ſlower than *Jupiter's*, who is not a little quicker in his Motion. And for the ſame Reaſon *Jupiter's* Regreſſions do oftner happen than thoſe of *Mars*; becauſe *Mars* moving faſter, deſcribes a greater Space in the *Zodiack*; ſo that there is more time neceſſary for him to come in *Oppoſition* to the *Sun*, than what *Jupiter* needs for that purpoſe.

When Retrograde.

Let AC be a Portion of the *Earth*'s Orbit, which is touched by the Right Line AN, in which we will ſuppoſe the ſuperiour *Planets* to be ſeen from the *Earth*, viz. *Mars* in ♂, *Jupiter* in ♃, and *Saturn* in ♄; and let KLMN be a Portion of the *Zodiack*. Then the place of *Mars* ſeen from the *Sun* is K, which is called his true or Heliocentrick Place. But an *Aſtronomer* on the *Earth* will obſerve him at the Point N, which is called his *Apparent* or *Geocentrick Place*; ſo likewiſe *Jupiter* ſeen from the *Sun*, appears in L, which is his true Place; but from the *Earth* his apparent Place is N. After the ſame manner the true Place of *Saturn* ſeen from the *Sun*, the Center of his Motion, is M; but his Place in the *Zodiack*, that is viſible from the *Earth* is N. The Arches KN, LN, MN, the Differences between the true and apparent Places of the ſuperiour *Planets*, are called the *Parallaxes* of the annual Orb in theſe *Planets*. Through the *Sun* S draw SO parallel to AN, and by the 29*th* of the 1*ſt* of *Euclid*, the Angles A♂S, A♃S, A♄S, will be reſpectively equal to the Angles KSO, LSO and MSO. But the Angle ANS is equal to the Angle NSO, whoſe Meaſure is the Arch NO, which will therefore be the Meaſure of the Angle ANS, which is the Angle under which the Semidiameter AS

The Parallax *of the Annual Orb.*

Plate XV. Fig. 2.

of the *Earth*'s Orbit is ſeen from the Starry Heavens. But this Semidiameter is nothing in reſpect of the great Diſtance of the Heavens or Stars; for from thence it would appear under no ſenſible Angle, and look like a Point. And therefore in the Heavens the Angle N S O, or the Arch N O vaniſheth, and the Points N and O coincide; and the Arches K O, L O, M O, are of the ſame bigneſs with the Arches K N, L N and M N, which are therefore the Meaſures of the Angles A ♂ S, A ♃ S, A ♄ S. But theſe Angles are as the apparent Semidiameters of the Orbit of the *Earth* ſeen from the reſpective *Planets*: And therefore in each of the ſuperiour *Planets* the *Parallax* of the Annual Orbit is equal to the Angle under which the Semidiameter of the Earth's Orbit is ſeen from that *Planet*; and the nearer any of them is to the *Earth* or *Sun*, ſo much the bigger is that Angle: And therefore this *Parallax* in *Mars* is greater than in *Jupiter*; and again, in *Jupiter* greater than it is in *Saturn*. But in the *fixed Stars* there can be no *Parallax* of the Annual Orb obſerved, it being ſo very ſmall.

The Retrogreſſions of Mars *greater than thoſe of* Jupiter; *and* Jupiter's *greater than* Saturn's.

IT is alſo evident from hence, that the Retrogreſſions of *Mars* are greater than thoſe of *Jupiter*, though they do not happen ſo often; ſo likewiſe *Jupiter* has his Retrogreſſions greater than thoſe of *Saturn*, and that upon a double Account: Firſt becauſe *Mars* is nearer to the *Earth* than *Jupiter*, and *Jupiter* nearer than *Saturn*; and likewiſe becauſe they move faſter.

HAVING the *Parallax* of the Annual Orb in any *Planet*, we can from thence eaſily find his Diſtance from the *Sun*, in reſpect of the *Earth*'s Diſtance from him: For in *Mars*, becauſe the Angle A ♂ S is given, being meaſured by the *Parallax* of the Annual Orb, and the Angle ♂ A S is found by Obſervation, being the viſible Elongation of *Mars* from the *Sun*: If we make the Proportion, As the *Sine* of the Annual *Parallax* is to the *Sine* of the Elongation, ſo let S A the Diſtance of the *Earth* from the *Sun* be to a Fourth, which will be ♂ S, the Diſtance of *Mars* from the *Sun*. This Annual *Parallax*, by which the *Planets* ſeem ſometimes to move faſter, ſometimes ſlower, in the Heavens, ſometimes to go *Eaſtward* and ſometimes *Weſtward*, produces in their Motions an Inequality, which, by the *Aſtronomers*, is called their *Second* or *Optical Inequality*, to diſtinguiſh it from their firſt Inequality which the *Planets* really have, by which they move in their Orbits with Motions that are not always the ſame. In the *Oppoſitions* or *Conjunctions* of theſe *Planets* with the *Sun*, this ſecond Inequality or *Parallax* vaniſhes; and their *Geocentrick* Places and the *Heliocentrick* coincide; or a *Spectator* in the *Sun*, and another in the *Earth* would obſerve the *Planet* in the ſame Point of the Heavens.

THE Angles A ♂ S, A ♃ S, A ♄ S, are nearly the greateſt Elongations of the *Earth* from the *Sun*, if ſhe were obſerved from the reſpective *Planets*, when the Line N ♂ A touches the *Earth*'s Orb in A. In *Mars* the Angle A ♂ S is about 42 Degrees; and therefore the *Earth* ſeen from *Mars*, never goes ſo far from the *Sun* as we ſee *Venus* does. In *Jupiter* the greateſt Elongation of the *Earth* from the *Sun* will be obſerved to be but 11 Degrees, and therefore is not ſo much as half the Diſtance we obſerve *Mercury* to depart from the *Sun*. In *Saturn* the Angle A ♄ S, or the greateſt Elongation of the *Earth* from the *Sun* that can be ſeen from that *Planet*, is but 6 Degrees, and not much above a fourth Part of the greateſt Elongation we obſerve in *Mercury*. And ſince *Mercury* is but ſeldom ſeen by us, a ſight of the *Earth* from *Saturn* may be a rare and unuſual Spectacle: Perhaps the *Saturnian Aſtronomers* have not yet diſcovered, that there is ſuch a Body as our *Earth* in the Univerſe.

The Attendants or Satellits of Jupiter *and* Saturn.

EACH of the two outmoſt of the *Planets* have a good Company of Attendants; for *Jupiter* keeps no fewer than four conſtantly by him, and *Saturn* five in his Retinue, which is a Sight no leſs wonderful than delightful. Theſe *Satellits*, like our *Moon*, do always accompany their primary *Planets* in their Circuits round the *Sun*; and in the mean time they perform their proper Circulations about their Primaries; and therefore they will have the ſame *Phaſes* and Figures that our *Moon* ſhews us: When they are in *Oppoſition* to the *Sun*, they appear to *Saturn* and *Jupiter* bright and full; from thence receding, they aſſume a gibbous Shape: When they come to a Quadrantile Aſpect, they look like Half-Moons; before the *Conjunction* they ſhew themſelves in horned Figures; and when they come to be joined in the ſame Line with the *Sun*, they totally diſappear.

THESE *Satellits*, ſeen from the *Earth*, though they go, at the furtheſt, but a little way from their Primaries, yet ſometimes they approach them nearer, and ſometimes remove a little further from them. Let ABT be the Orbit of the *Earth*, in the middle of which the *Sun* reſides. Let EF be a Portion of the Orb of *Jupiter*, in which let *Jupiter* be in ♃, who keeps in the middle of the Orbits of his four Attendants. Theſe *Satellits* or *Moons*, when they deſcribe the inferiour Parts of their Orbits LMN, ſeen from the *Earth* or *Sun*, will appear to have a Motion *Weſtward*; but while they are moving through the ſuperiour Portions GHK, we obſerve them to move *Eaſtward*, according to their true Motions. Now when their viſible Motion is *Eaſtward*, they are twice hid from us; once in O behind the Body of *Jupiter*, that is, in the Right Line which joins the Centers of the *Earth* and *Jupiter*; and again they vaniſh and become inviſible when they fall into the Shadow of *Jupiter*, or are in the Right Line which joins the Centers of the *Sun* and *Jupiter*, and then they ſuffer Eclipſes, which is always when they are at their Full, as ſeen from *Jupiter*: theſe Eclipſes happening in the ſame manner as they do to our *Moon*, by the Interpoſition of the *Earth* between the *Sun* and it.

Plate XV. Fig. 3.

WHEN *Jupiter* is to the *Eaſt* of the *Sun*, and is ſeen in the Evening after Sun-ſetting, that is, when the *Earth* is in A, they are firſt hid behind

Jupiter, becauſe of their viſible *Conjunction* with *Jupiter*, before they fall into his Shadow; and their ſecond diſappearing is in the Eclipſe, upon their entring the Shadow. But when *Jupiter* is more *Weſterly* than the *Sun*, as he appears after *Conjunction*, when he is only ſeen in the Morning, that is, when the *Earth* is about B, then they fall into *Jupiter*'s Shadow at V and are eclipſed, before they are hid behind his Body in P. But when theſe *Moons* have a Retrograde Motion, that is, when they are ſeen to go *Weſtward*, and deſcribe the inferiour Parts of their Orbits, then they only once diſappear in Q, when they cannot be diſtinguiſhed from the Body of *Jupiter*: But when the *Satellits*, ſeen from the *Sun*, are in their inferiour *Conjunction* with *Jupiter*; or as ſeen from *Jupiter*, they are in *Conjunction* with the *Sun*, their Shadows will fall upon *Jupiter*; and ſome part of the Disk of *Jupiter* will be in an Eclipſe; and a *Spectator* within the Shadow would obſerve a total Eclipſe of the *Sun*. We have already given the Diſtances and Periods of all the *Jovial* and *Saturnian Moons*, at the End of our third Lecture.

The Parallax *of the Annual Orb, and the Diſtance of* Jupiter *from the* Sun *determined by the Eclipſes.*

BY the Motions and Eclipſes of theſe *Moons*, the *Parallax* of the Annual Orb in *Jupiter*, and his Diſtance from the *Sun* may be eaſily known. For, let POR be the Orbit of any *Satellit*; for Example, the outermoſt; and ſuppoſe the *Earth* in the Point of its Orbit A, the time muſt be obſerved when the *Satellit* lies hid behind *Jupiter*'s Body in O: For which purpoſe the Moment of Time muſt be carefully mark'd when he firſt diſappears, and then alſo the Moment he becomes again viſible; the middle Moment between theſe two, is the time when the *Satellit* is in O, or in the Line which paſſes through the Centers of the *Earth* and *Jupiter*. After the ſame manner obſerve when the *Satellit* is in the middle of an Eclipſe, or in the middle of *Jupiter*'s Shadow, that is, when it is in V; by this means we ſhall have the time it takes to deſcribe the Arch OV. And becauſe his Motion about *Jupiter* is equable, and his

Lectue XVI.

Periodical Time known, we can from thence find out the Arch O V; for this *Planet* revolves about *Jupiter* in 402 Hours. Let us ſuppoſe the time he takes to move from O to V be 12 Hours; ſay, As 402 Hours is to 12 Hours, ſo are 360 Degrees to a fourth Quantity, which will be found to be 10 Degrees 44 Minutes. And therefore the Arch O V is 10 Degrees 44 Minutes. But this Arch O V is the Meaſure of the Angle O ♃ V, or of the Angle which is equal to it A ♃ S; and the Arch which meaſures this Angle is the *Parallax* of the Annual Orb, which therefore is known. In the Triangle therefore A ♃ S we have the Angle at ♃, and alſo the Angle at A the Elongation of *Jupiter* from the *Sun*, which may be had either by a Calculation from Aſtronomical Tables, or by Obſervation. Beſides, we have the Side A S, the Diſtance of the *Earth* from the *Sun*, which we aſſume to conſiſt of 100000 Parts. Since therefore in this Triangle we have all the Angles and one Side, by *Trigonometry* we ſhall find the other Sides, and particularly *S* ♃ the Diſtance of *Jupiter* from the *Sun*; ſo likewiſe we may find A ♃ the Diſtance of *Jupiter* from the *Earth*, which is always variable. But for the nice Determinations of theſe Diſtances, it may be needful to have ſeveral, and thoſe very accurate Obſervations, made by the Skilful, and taken by the help of the beſt Teleſcopes.

Whether Light be propagated in an Inſtant, or in Time?

BY the Eclipſes of *Jupiter*'s *Moons* we are able to give a Solution of a Problem, which is the moſt noble and curious in Natural Philoſophy, which cannot but raiſe our Wonder and Amazement; that is, Whether Light be propagated to us in an Inſtant; or if its Motion be ſucceſſive, and if it takes ſome Time to arrive from the *Sun*, or any diſtant Object to us? Now theſe Eclipſes do ſhew us, that there is no inſtantaneous Motion in Light, though it comes from the Heavens to us with a prodigious quick Motion, and incredible Celerity.

This Queſtion determined by the obſervation of the Eclipſes of Jupiter's Moons.

FOR if the Motion of Light were in an Inſtant, when the *Earth* is at T, at his greateſt Diſtance from *Jupiter*, an *Aſtronomer* here would obſerve an Eclipſe of a *Satellit* at the ſame Moment of time he would do, were the *Earth* at X at her neareſt Diſtance to *Jupiter*: For, according to this *Hypotheſis*, Light is propagated in the ſame Inſtant through all Spaces indefinitely, whether near, or never ſo much remote. But if Light takes up any time for its Propagation through Space, it will ſooner paſs through a ſhorter Space than a greater. And therefore an Obſervator at X being nearer to *Jupiter* than one at T, by the Diſtance X T, which is almoſt equal to the Diameter of the *Earth*'s Orbit, will ſooner obſerve the Eclipſe of a *Satellit* than a *Spectator* can do at T. And therefore from the Difference of thoſe Times, which is proportional to X T the Difference of Diſtances, we can collect the Velocity of Light; and ſo this Matter is in Reality. For whenever the *Earth* is at its neareſt Diſtance from *Jupiter*, the Eclipſes are found to happen ſooner than they do when they are obſerved from T at a greater Diſtance, where they fall out ſenſibly later than they ought to be, according to our Aſtronomical Computations. Theſe quicker and ſlower Returns of Eclipſes having been obſerved for many Years by Mr. *Romer* with much Care and Diligence, upon them he founded his Argument for demonſtrating the ſucceſſive Propagation of Light; and by them he proved, That Light, like all other Bodies in Motion, had a determined Degree of Velocity, and took a determined Time to move through a given Space. To which Opinion the moſt Part of the *Aſtronomers* and *Philoſophers* do now give their Aſſent.

THE Particles therefore of Light, though their Minuteneſs be indefinite and not eaſily to be imagined, yet they have a progreſſive Rectilinear Motion, and are not diffuſed as by the Waves of any *Medium* or Fluid. *Romer* determines the Velocity of Light to be ſuch, that it reaches us here from the

Sun in the Space of 11 Minutes: But that Diſtance does not ſeem to be leſs than 50000000 Miles; which Space Light paſſes thro in ſo ſmall a time, that ſo prodigious a Velocity cannot eaſily be conceived by us, which ſo much exceeds the Velocity of the ſwifteſt Bodies we know. For though the *Earth* has a very quick Motion round the *Sun*, yet its Velocity, compared with the Velocity of Light, is no more than that of a Snail, in Compariſon of the Swiftneſs of the *Earth*.

The Longitude of Places determined by the Obſervations of theſe Eclipſes.

FROM the Eclipſes of *Jupiter's Moons*, we have likewiſe this Advantage, that when they are obſerved in different Places of the *Earth*, the Longitude of Places are by ſuch Obſervations determined. But that this Method of finding the Longitude may be more eaſily underſtood, we muſt firſt lay down ſome few Principles.

IF through the *Poles* of the *Earth* and any Place, there be drawn a great Circle upon its Surface, this Circle, by the Rotation of the *Earth*, will be turned round the *Earth's Axis*: And when the Plane of this Circle produced paſſes thro' the Body of the *Sun*, all the Inhabitants which live under this Circle, will then obſerve the *Sun* to come into their Meridian, and they will have Mid-day; from whence this Circle has the Name of a Meridian, from the *Latin* Word *Meridies*, which ſignifies Mid-day. Now if we imagine another Meridian placed more *Weſtwardly*, which with the former makes an Angle of 15 Degrees, the Plane of this Meridian will paſs through the *Sun* one Hour later than the former did; and therefore when the Inhabitants under this Meridian reckon Mid-day, the Inhabitants under the firſt will reckon one Hour after Mid-day. If there be a Meridian which makes an Angle of 30 Degrees with the firſt we mentioned; then when they that live under this Meridian have Mid-day, thoſe that live under the firſt will reckon two of the Clock after Mid-day; and ſo for every 15 Degrees of the Equator which lies between the two Meridians, ſo many Hours more do they reckon, who live under the more *Eaſtern* Meridian, than they who live under the *Weſtern*. And after the ſame manner for every Degree of the Equator between Meridians, the *Eaſtern* People are four Minutes ſooner in their Reckoning than the *Weſtern*; and for every 15 Minutes of a Degree, they reckon one Minute in Time. As for Example, If the Arch of the Equator between the two Meridians conſiſts of 85 Degrees, dividing 85 by 15, the Quotient $5\frac{2}{3}$ ſhews, that under the more *Eaſterly* Meridian they reckon the fifth Hour and 40 Minutes, when they under the *Weſtern* Meridian have Mid-day. And when the *Eaſtern* People have Mid-day, thoſe to the *Weſt* will reckon their Time to be the ſixth Hour and 20 Minutes in the Morning; and the Difference between the Hours which are reckon'd under theſe two Meridians, will always be $5\frac{2}{3}$, if the Arch of the Æquator intercepted between them be 85 Degrees.

ON the contrary, having the Difference of the Hours which are reckon'd under two different Meridians for the ſame Moment of Time, we ſhall by this Difference find the Arch of the Equator intercepted between them; which Arch is called the *Difference of Longitude* of the Places under thoſe Meridians, when the Longitudes are computed from one fixed and ſettled Meridian, which is called the *firſt Meridian*: And this Arch is found by multiplying the Difference of the Hours by 15, and the Product ſhews the Degrees. So likewiſe if the Minutes of Time be multiplied by 15, and the Product, if it exceed 60, be divided by 60, the Quotient and Reſidue will give the Degrees and Minutes that are further to be added to the former, and which make up the Difference of Longitude of the Places. For Example, Suppoſe the Difference of the Hours to be 7 and 22 Minutes; 7 multiplied by 15 is 105, and 22 by 15 is 330 Minutes; which divided by 60, gives 5 Degrees 30 Minutes: And therefore the whole Difference of Longitude is 110 Degrees 30 Minutes. Theſe things being noted, IF in two different Places the Beginning of an Eclipſe of any of *Jupiter*'s *Moons* be obſerved, and the Times marked when this Beginning happened; according to the Times of the reſpective Places, the Difference of Hours converted into Degrees and Minutes of the Equator, will ſhew the Difference of Longitude of thoſe Places.

IF we had *Ephemerides* of the Motions and Eclipſes of *Jupiter*'s *Moons*, accurately computed for any Meridian; inſtead of an Obſervation in another Place, we might conſult the *Ephemerides*, which tell when the Eclipſe is to be obſerved in that Place; and we might take from them the Hours and Minutes when the Eclipſe happens in that Place; and this time compared with the Time the Eclipſe is obſerved in any other Place, will give the Difference of Times in thoſe two Places: And from thence we can find out the Difference of their Longitudes, as before. The Longitude of Places may likewiſe be found by Obſervations of Eclipſes of the *Moon*, or the *Appulſes* of the *Moon* to the *fixed Stars*, obſerved from ſeveral Places: But theſe are Appearances that are more ſeldom to be obſerved than are the Eclipſes of the *Satellits* of *Jupiter*.

Upon Land the Eclipſes are eaſily obſerved, and the Longitudes found, but not at Sea.

UPON Land and firm Ground the Eclipſes are eaſily obſerved; and if they could be as eaſily obſerved at Sea, the Art of Navigation would be brought almoſt to perfection, and liable to no Errors in Computation; but at Sea the Motion and toſſings of the Ship renders all Obſervations of ſuch Eclipſes impracticable. And therefore, if any could find a Method for determining the Longitude of a Ship at Sea at any time, he would then oblige the Seamen with a Diſcovery, by them more deſired than any thing elſe in Navigation; and which would be ſo uſeful to the Publick, that the Parliament hath thought fit to allow a large Reward of 20000 Pounds to the Diſcoverer. Upon which, many, tempted by ſo great a Reward, have ſpent much Labour and Thought, for to make the Diſcovery, but to no purpoſe: For

no

Plate XV

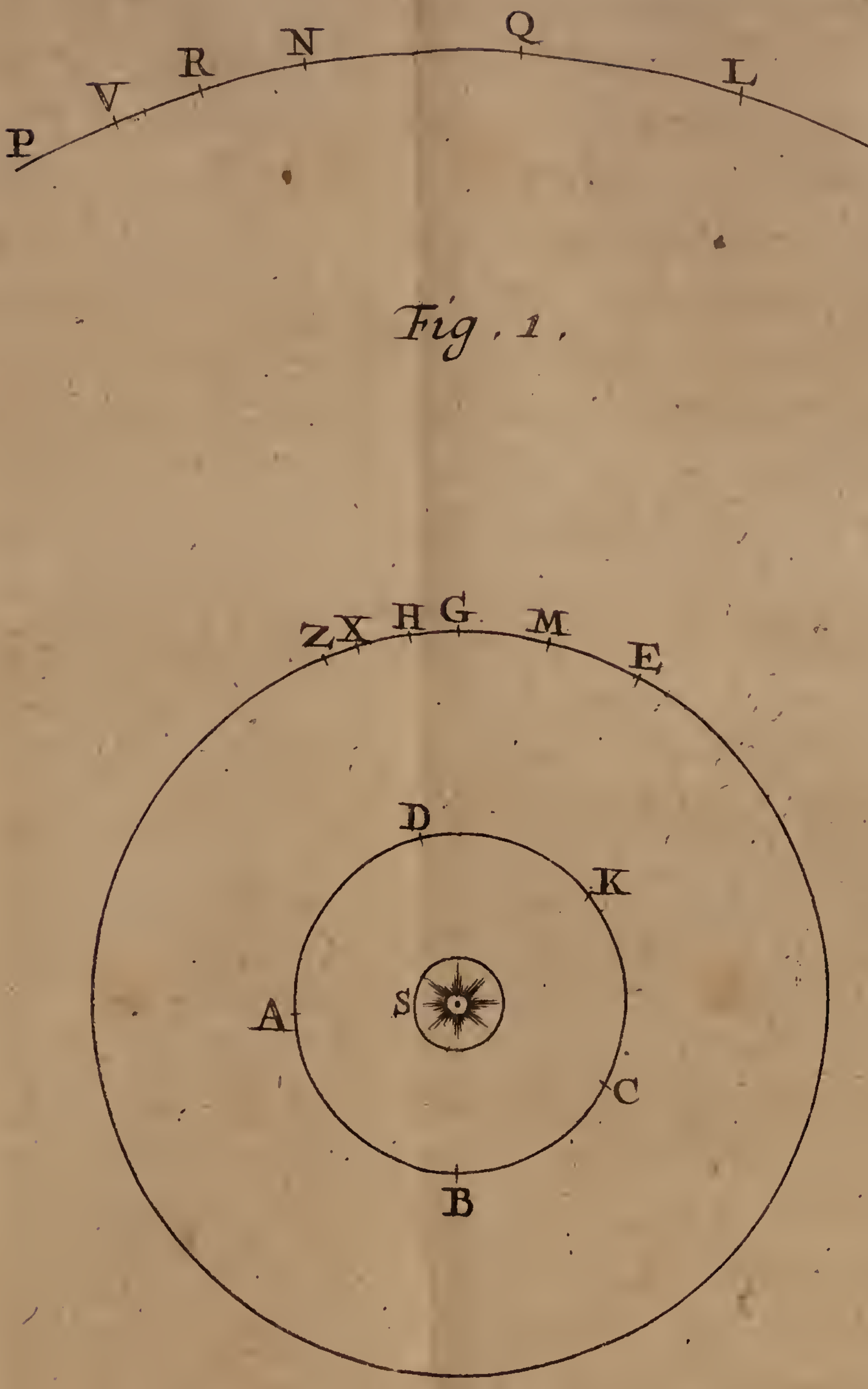


Fig. 1.

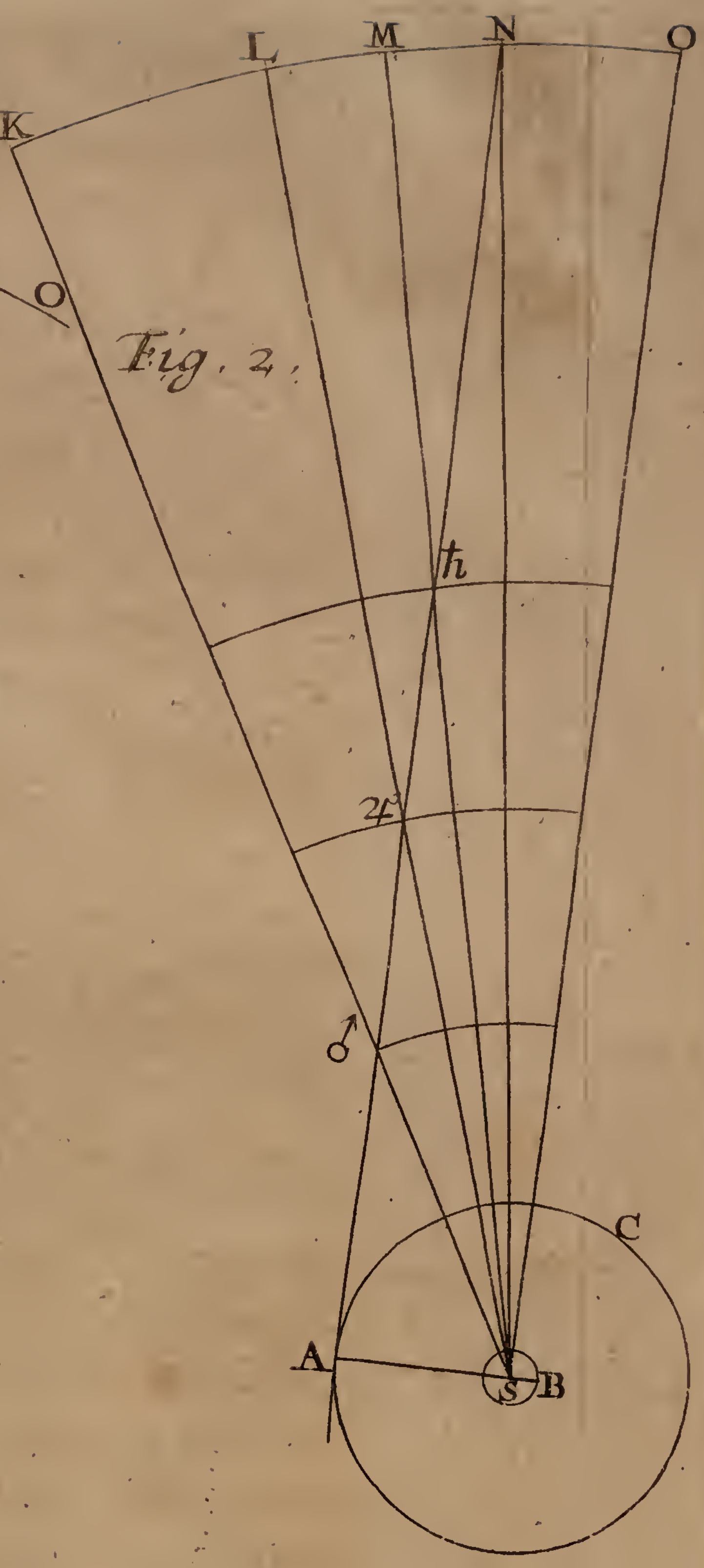


Fig. 2.

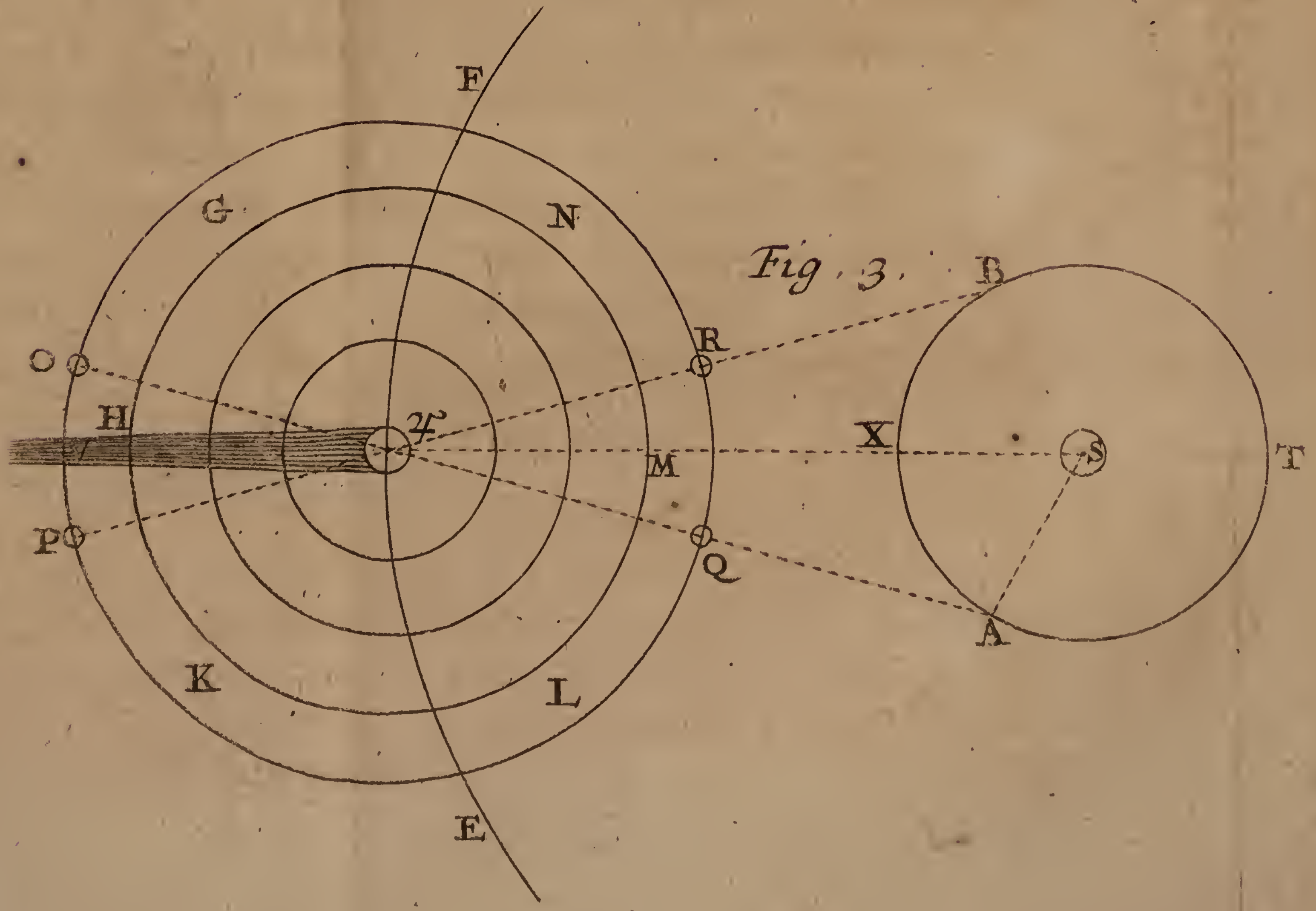


Fig. 3.

no Man has hitherto been able to lay hold on the Reward, though they have propoſed many different Methods and Ways of attaining it. Many being much in Love with their own Inventions, imagining that they had certainly found it, have demanded the Reward promiſed to the Diſcoverer; but yet moſt of theſe Men have been ſo ignorant that they have ſcarce known what it is to find the Longitude.

LECTURE XVII.

Of COMETS.

Comets are a ſort of Planets.

The Philoſophers Opinion of Comets.

BESIDES the ordinary *Planets*, which are always in our Neighbourhood, and within our View, there are another ſort of *Planets* which may be called *Temporary*; which are conſpicuous only for a Seaſon, after which they again withdraw, and are no longer viſible. The ancient Philoſophers allowed them a Place in the heavenly Regions, and ranked them in Stations far above the *Moon*. For *Ariſtotle*, *Seneca*, *Plutarch* and others teſtifie, That the *Pythagoreans*, and the whole *Italian* Sect maintained, that a Comet was a kind of *Planet* or *wandering Star*, which appeared again after a long Interval of time. *Hippocratis Chius* was of the ſame Opinion, as *Ariſtotle* informs us: The ſame was the Opinion of *Democritus*, as we are told by *Seneca* in his *Natural Queſtions, Book* VII. *Chap.* 3. For, ſays he, "*Democritus* the moſt curious "and ſubtile of all the Ancients, ſuſpected, that "there were many more *Stars* which moved, un"derſtanding by them the Comets; but he neither "eſtabliſhed their Number or their Names, the

" Courſes of the five *Planets* not having as yet " been diſcovered. Again, *Seneca* aſſures us, That *Apollonius Myndius*, one of the moſt skilful Philoſophers in the Search of Natural Cauſes, did aſſert, That the *Chaldeans* reckon'd Comets among the other *wandring Stars*, and that they knew their Courſes. *Apollonius* himſelf maintained, That a Comet was a *Star* of its own kind, as the *Sun* and *Moon* are, but that its Courſe was not yet known: That by its Motion it mounts very high in the Heavens, and only appears when it deſcends into the lower Part of its Orb. And *Seneca* himſelf imbraces this Opinion: 'I cannot believe, ' ſays he, that a Comet is a Fire ſuddenly kindled, ' but that it ought to be ranked among the Eter' nal Works of Nature. A Comet has its proper ' Place, and is not quickly to be moved from ' thence; it goes its Courſe, and is not extinguiſh' ed, but runs off from us. But you will ſay, if ' it were a *wandering Star* it would keep in the Zo' diack: But who can ſet one Boundary to all the ' *Stars*? Who can reſtrain the Works of the Divi' nity to a narrow Compaſs? For each of thoſe Bo' dies which you imagine to be the only that have ' Motion, have very different Circles; why there' fore may there not be ſome that have peculiar ' Ways of their own, wherein they recede far from ' the reſt? But that their Courſes may be known, ' it is neceſſary to have a Collection of all the an' tient Obſervations about Comets; for their Ap' pearances are ſo rare, that their Orbits are not yet ' determined; nor can we as yet find if they have ' their Periods, and if they return again in a cer' tain Order." At laſt he thus prophecies. 'The ' time will come wherein theſe things which are ' now hid from us, will be diſcovered; which ' Obſervation, and the Diligence of after-Ages will ' find out; for it is not one Age that is ſufficient ' for ſo great matters. The time will be when Po' ſterity will wonder that we were ignorant of things ' ſo plain: One will ariſe who will demonſtrate in ' what Regions of Space the Comets wander, why 'they recede ſo far from the other *Planets*, how 'great, and what ſort of Bodies they are.

The Peripateticks *ſuppoſed Comets to be Meteors generated in the Air.*

BUT for all this, the whole Sect of *Peripateticks*, fearing that Generations and Corruptions ſhould be introduced into the Heavens by placing the Comets in them, thruſt all the Comets down into the Sublunary Regions, and would maintain, that they were nothing but a kind of Meteors. But the *Phænomena*, or the Manner theſe Comets appear in, will not ſuffer them to have a Place ſo low, and ſo near to us. For it is clear, that they are not generated in our Atmoſphere, becauſe they are certainly far higher than it reaches: For Comets are to be ſeen at the ſame time from different Places of the *Earth*, which are at great Diſtances from one another, which cannot happen to any Body that reſides within our Atmoſphere, which is not extended upwards above Fifty Miles.

Comets are higher than the Moon.

BUT that Comets are not only above the Air, but alſo beyond the *Moon* is plain; becauſe Comets ſeen from different Places, are obſerved to be at the ſame Diſtance from a *fixed Star* which is near them. As for Example, the Comet which *Tycho Brahe* obſerved at *Uraniburg*, was likewiſe ſeen by *Hagecius* at *Prague* in *Bohemia* at the ſame time; which two Places differ 6 Degrees in Latitude, and are nearly under the ſame Meridian; and both meaſured the Diſtance of this Comet from the *Star* we call the *Vultur*; that is, how much it was below it towards the Horizon; for both the *Vultur* and it were in the ſame Vertical Circle, and both Obſervators found their Diſtance the ſame, and conſequently they both viewed the Comet in the ſame Point of the Heavens; which could not be, unleſs it had been higher than the *Moon*.

Plate XVI. Fig. 1.

A Demonſtration that Comets are higher than the Moon.

LET the Circle ABG repreſent the *Earth*, in which let *Uraniburg* be in A, and *Prague* at B: let D be the Place of the Comet: let FCE be the Firmament of the *fixed Stars*, in which let the *Star* F be the *Vultur*; the Place of the Comet ſeen from *Uraniburg* among the *Stars* is E, and its Diſtance from the *Vultur* is the Arch FE; but the Comet ſeen from *Prague*, appears in C; and its Diſtance from the *Vultur* is the Arch FC, which is leſs than the Arch FE. But by Obſervation it has been found, that this Comet ſeen from both theſe Places, ſeemed to be at the ſame Diſtance from the *Vultur*; and therefore the Arches FE and FC are equal, or rather the ſame. So great therefore is the Diſtance of the Comet from the *Earth*, that the Arch CE vaniſheth, and is altogether imperceptible: But the *Moon* ſeen from theſe two Places would appear to have different Diſtances from the *Vultur*; and ſo therefore would a Comet, were it as near as ſhe is: This Comet therefore was further diſtant off than the *Moon*.

The true and the apparent Place of a Comet.

A Comet ſeen from the Center of the *Earth*, would appear in G; but from the Surface of the *Earth* at A it is obſerved in E: The firſt is called the *Comet*'s *true Place*, and the ſecond, its *apparent Place*; and the Diſtance GE between the true and apparent Place, is called the *Parallax* of the Comet: by it a Comet is always depreſſed more towards the Horizon, than it is in its true Place. Now the *Parallax* of any *Star* is always equal to the Arch which meaſures the Angle, that the *Earth*'s Semidiameter, paſſing through the place of the Obſervator, is ſeen under from the Comet; as we ſhewed before when we treated of the *Parallax* of the *Moon*.

Its Parallax.

NOW if there be no ſenſible *Parallax*, the Angle under which the Semidiameter of the *Earth* is ſeen from a Comet, will not be ſenſible; and therefore the Comets muſt needs be at a vaſt Diſtance from us, ſince the *Earth* ſeen from thence appears no bigger than a Point.

A Way to find if a Comet has a ſenſible Parallax.

BY the help only of a Thread, in matter of ſo great Nicety, we may find out if a Comet have any ſenſible *Parallax*: For a Comet, juſt before it diſappears, goes ſo ſlowly, that it ſcarce ſeems to move; and it may be twice obſerved in this manner:

ner: Firſt, when it is very high above the *Horizon*, take any two *Stars* between which the Comet lies in a Right Line parallel to the *Horizon*, which, by extending the Thread directly before the *Stars*, may be eaſily tryed: afterwards when the Comet approaches near to the *Horizon*, by extending the Thread we muſt again try, if it ſtill keeps in a Right Line between the ſame two *fixed Stars*. Now if there be any ſenſible *Parallax* which depreſſes the Comet, it cannot be ſeen in the ſame Right Line as before; and therefore if it keeps the ſame Poſition as to thoſe *Stars*, it is a convincing Argument that the Comet has no ſenſible *Parallax*, and muſt therefore be at a prodigious Diſtance from us. We need not here fear any Error ariſing from Refraction, which always raiſes the *Stars*, and makes them appear more elevated above the *Horizon* than they are; for this Refraction equally affects both Comet and *Stars*, and therefore it will not change their Poſitions in reſpect of one another.

Another Method for the ſame.

A Comet may likewiſe be obſerved when it is near the *Eaſtern* Part of the *Horizon*, and in a Right Line with two *Stars* that are both in the ſame Circle which is perpendicular to the *Horizon*: And afterwards, when the *Stars* riſe higher, and are not in the ſame Vertical Circle as before, if it appear ſtill to be in the ſame Line with them, it can have no ſenſible *Parallax*; and therefore its Courſe muſt be very high in the Heavens. But if it ſhould be found more depreſſed than to appear in the Right Line that joins the *Stars*, then the Comet muſt needs have a *Parallax*. If while theſe Obſervations are making, the Comet ſhould have a proper Motion of its own, there muſt be made an Allowance for that Motion, according to the time between the two Obſervations.

Comets are affected with the Parallax *of the Annual Orb.*

AS the want of a Diurnal *Parallax* was an Argument for placing Comets above the *Moon*, ſo their being ſubject to the *Parallax* of the Annual Orb is a convincing Proof of their deſcending into the Planetary Regions; for Comets which have a Motion forward, according to the Order of the Signs, near the time of their diſappearing, are all of them either ſlower than uſual, or even Retrograde, if the *Earth* be between the *Sun* and them; or they are quicker than ordinary in their Motions when the *Sun* is between the *Earth* and them; and they appear in *Conjunction* with the *Sun*, as the *Planets* are obſerved to do. On the contrary, thoſe Comets which have their proper Motions Retrograde, or contrary to the Order of the Signs, are quicker than uſual when they begin to withdraw themſelves, and diſappear when the *Earth* is between the *Sun* and them; or elſe they ſlacken their Pace, and ſeem to move more ſlowly when the *Earth* is in the oppoſite Poſition. Theſe Changes in their Motions ariſe from the Motion of the *Earth*, and its various Poſition, as in the *Planets*, who, according as the Motion of the *Earth* agrees with theirs, or is contrary to it, ſometimes appear to go with a Retrograde Motion, ſometimes they go ſlower, and ſometimes with a quicker Motion.

When a Comet is ſeen Retrograde.

IF the *Earth* move the ſame way as the Comet does, and hath an Angular Motion round the *Sun* quicker than it, ſo that the Right Lines which conſtantly joins the *Earth* and Comet, all converge to points beyond the Comet; this Comet ſeen from the *Earth*, upon the account of his ſlower Motion, will appear Retrograde: But if the Motion of the *Earth* be leſs than that of the Comet, the Motion of the *Earth* takes off from the viſible Motion of the Comet, and then the viſible Motion of the Comet ſeems to be ſlower. But when the *Earth* and Comet have contrary Motions, the Comet's apparent Motion is thereby accelerated.

WE infer the ſame thing from the Curvature of a Comet's Way, for they generally ſeem to move in great Circles almoſt as long as their Motion is ſwift. But at laſt when that part of their apparent Motion which ariſes from the *Parallax* of the Annual Orb, bears a greater Proportion to their whole apparent Motion, then they uſe to deviate from moving in a great Circle; and when the *Earth* moves one way, they go the contrary: This Deflection or Deviation ariſes chiefly from the *Parallax* of the Annual Orb, and exactly anſwers to the Quantity of the *Earth*'s Motion. And by Obſervation it has been found in ſome Comets ſo great, as ſufficiently to prove that they have deſcended far below *Jupiter*: And in their *Perigeons* and *Perihelions*, when they are neareſt to us, they often come within the Orbit of *Mars*, and even the Orbits of the inferiour *Planets*.

WHEN the Comets recede from the *Earth*, and approach the *Sun*, their Luſtre and Light is encreaſed, although their apparent Diameters be diminiſhed upon account of their further Diſtance from us.

The Figures of Comets.

THE Figures of Comets are obſerved to be very different; for ſome of them throw forth Beams like Hair every way round them, and theſe are called *Hairy Comets.* Others again have a long Beard, or rather a fiery Tail oppoſite to the Region in which the *Sun* is ſeen; and they are called *Bearded*, or *Comets with Tails.* Their Magnitude has alſo been obſerved to be very different; many of them, without their Hair, appear no bigger than *Stars* of the firſt Magnitude. But ſome Authors have given us an Account of others which were much greater; ſuch was that which appeared in the time of the Emperor *Nero*, which, as *Seneca* relates, was not inferiour in Magnitude to the *Sun* itſelf. So the Comet which in the Year 1652. *Hevelius* obſerved, did not ſeem to be leſs than the *Moon*, though it had not ſo bright a Splendor; for it had a pale and dim Light, and appeared with a diſmal Aſpect. Moſt Comets have a denſe and dark Atmoſphere ſurrounding their Bodies, which weakens and blunts the *Sun*'s Rays that fall upon it; but within it appears the Kernel or ſolid Body of the Comet, which, when the Clouds are diſperſed, gives a ſplendid and briſk Light.

Comets have their Apparent diurnal Motion from Eaſt *to* Weſt.

COMETS, ſince they are at ſuch a diſtance from the *Earth*, like all other *Stars*, muſt have the Apparent Motion round the *Earth* from *Eaſt* to *Weſt*, which ariſes only from the Rotation of the *Earth* round its *Axis*. But beſides this they have a real and proper Motion of their own, by which they are continually ſhifting their place in the Heavens, and have their proper courſes in the Celeſtial Regions. The Antients were not ignorant of ſuch a Motion, for they never had reckoned them among the wandring *Stars*, unleſs they had known that like the *Planets*, they had their peculiar Courſes: *Seneca* acknowledged and obſerved that they had ſuch a Motion, and ſaid that their way was in a Right Line, or as the *Aſtronomers* uſe to ſay, in a great Circle. For in the Seventh Book of his Natural Queſtions, Chap. 8. he ſays, 'that the Courſe of a Comet is 'eaſy and quiet, that it takes a determined way: 'That Comets do not proceed in a confuſed and 'tumultuous manner, as ſome believe, nor are they 'driven by Turbulent and uncertain Cauſes. In his 29th Chap. he mentions two Comets, one of which in the ſpace of ſix Months paſſed thro' one half of the Heavens: Another in the Time of the Emperor *Claudius*, was firſt obſerved towards the *North*, which by Degrees aroſe directly higher and higher, 'till it quite diſappeared.

They have likewiſe a proper Motion of their own.

The Method of finding the Courſe of a Comet.

BY the means of a Celeſtial Globe, in whoſe Surface the *Stars* are rightly placed and painted, by a Mechanical Method the way of a Comet may be eaſily traced in the Heavens. Let there be every Day obſerved four *Stars* which are round the Comet, and let them be ſuch as the Comet may be in the Right Lines which joins the two oppoſite *Stars*; which may eaſily be found out by the means of a Thread placed before the Eye, and extended over againſt the *Stars* and Comet: For Example, let the Comet's place be A, between the four *Stars* B, C, D, E, ſo that the Line joining the *Stars* B and D may paſs thro' the Body of the Comet; and ſo likewiſe the Lines paſſing thro' the

Plate XVI. Fig. 2.

the *Stars* C and E. And therefore upon a Globe in which are marked theſe four *Stars* in their proper places, extend one Thread thro' the *Stars* B and D, and another thro' the *Stars* C, E, and the Interſection of the Threads will give you the place of the Comet. If this be daily done, and the place of the Comet be every Day taken, by this means we ſhall manifeſtly find out the Courſe a Comet takes in the Heavens, which will be found to be a great Circle; for all the Points thus mark'd will be found to fall on the Periphery of a great Circle: And having any two Points of this Circle, we ſhall find its inclination to the Ecliptick, and the places of the *Nodes*; for it is only obſerving where a Thread ſtretched thro' the two Points cuts the Ecliptick.

Another way of doing the ſame.

The Courſe of a Comet appears nearly be in a great Circle.

THERE is another way of finding out the proper courſe of a Comet, by obſerving every Day its diſtance from two *fixed Stars*, whoſe Longitudes and Latitudes are known; from which diſtances we can compute the places of the Comet; and theſe places being marked on the Surface of a Celeſtial Globe, will manifeſtly ſhew that the Courſe of a Comet is in a Portion of a great Circle, excepting that the Motion of the *Earth* will make it appear to deviate a little from it.

The Motion of Comets is in Planes which paſs thro' the Eye or the Sun.

Their Courſes various.

HENCE it is manifeſt that the Motion of a Comet is in a Plane, which paſſes thro' the Eye of the Spectator, or more exactly which paſſeth thro' the *Sun*, for all viſible Motion that is made in ſuch a Plane, however it be inclined to the Ecliptick, will always appear to be in the Periphery of a great Circle. Moreover, the Motion of a Comet is regular and orderly, and tho' it is unequal, yet there is a certain exact order obſerved in the very inequality of Motion. The proper Motion of Comets is not the ſame in all, but each has its peculiar Courſe: Some go from the *Weſt* to the *Eaſt*, others from *Eaſt* to *Weſt*, contrary to the order of the Signs, and their direction is contrary to the way the *Planets* take, who all move from *Weſt* to *Eaſt*: All of them that exactly obſerved, turn *Southwards* or *Northwards*, with different inclinations to the Ecliptick; and they are not like the *Planets* to be comprehended within the *Zodiack*, but they quickly depart out of it, and with various Motion paſs thro' all the Regions of the Heavens, ſome with a quicker, ſome a ſlower Motion: The greateſt Velocity that any we have yet ſeen has had, was that which was obſerved by *Regiomontanus*, which Comet moved in one Day fully forty Degrees. Some are ſwifteſt in the beginning of their appearance, and ſlacken their pace as they begin to vaniſh. Others again in the beginning and end of their Appearance have ſlow a Motion; but in the middle Time they are carried with a greater Velocity.

Comets deviate from a Courſe in a great Circle.

IT his been obſerved that ſome Comets for a few Days before they diſappeared, did not keep their Courſe exactly in a great Circle, but did ſomewhat deviate from it, ſo that the Angle of the Comets Orbit and the Ecliptick, was found to be different at laſt from what it was at firſt: But this deflection was only apparent, and did not ariſe from the real Motion of the Comet, but from that of the *Earth*, as we ſhewed in the Inferiour and Superiour *Planets*; whoſe diſtance and Inclination to the Ecliptick is various, according to the different Poſition of the *Earth*, whereas if they were obſerved from the *Sun*, any one of them would always appear to move in the ſame great Circle.

The true Line that a Comet deſcribes.

ALTHO' the Motion of a Comet appears to be in a great Circle, yet its true way may be quite different from a Circle, and may be in very various and different Lines, as either a Right Line, an Elliptick, Parabolick, or Hyperbolick Curve; or it may be any other Curve deſcribed in the ſame Plane: for all Motions in whatever Line the moving Body takes, when it lies in a Plain paſſing thro' the Eye, will always be obſerved to be performed in a great Circle. Many *Philoſophers*, and not a few *Aſtronomers*, have maintained that the Comets Motions are Rectilinear; But that which anſwers beſt to their Appearances is a Motion in a Parabolick or Elliptical Orbit. And if their Orbits be Elliptical, they are extreamly excentrick, ſo that their greater *Axis* bears a very conſiderable Proportion to their leſſer; upon which account they differ very much from the *Planets*, which tho' they move in Elliptical Orbits, yet they are ſo little excentrick, that they differ but a ſmall matter from Circles: Now the *Sun* reſides in the common *Focus* of the Orbits of both Comets and *Planets*. And the Comets obſerve the ſame Law in their Circulations round the *Sun* as the *Planets* do, that is, they move at ſuch a rate in their Orbits, that the Line which joins the *Sun* and them, does always deſcribe Areas or Spaces proportional to the Times; And therefore upon the ſame account as the *Planets*, they likewiſe muſt have a Gravity or Propenſion towards the *Sun*.

The Comets when they become viſible, when inviſible.

WHEN the Comets come to the inferiour Parts of their Orbits, and deſcend towards the *Sun*, or are juſt aſcending from him, then only they become viſible; afterwards departing from the *Sun*, and aſcending higher in their Orbits, they run out into far diſtant Regions, and withdraw themſelves from our Sight: for upon the account of their going further off the *Sun*, the Light they receive from him is thereby much weakned; and becauſe likewiſe of their greater diſtance from us, their Apparent Diameters become conſtantly leſs, till at laſt they vaniſh into a Point, and become inviſible. In their *Aphelions* whither they run out into far diſtant Regions, becauſe of the great Excentricity of their Orbits, they have a very ſlow Motion; but in their *Perihelions* where they come near the *Sun*, they move with a quick pace.

LET S be the *Sun*, A P D G the Elliptick Orbit of a Comet; TCE the Orbit of the *Earth*. If we ſhould ſuppoſe the *ſemi-Axis* of the Comet's Orbit to be 100 times greater than the *ſemi-Axis* of the *Earth*'s Orbit, or which is the ſame, than

Plate XVI. Fig. 3.

its mean diſtance from the *Sun*, that Comet would not compleat its Revolution in leſs than 1000 Years; for the Squares of the Periodical Times of the *Earth* and Comet, muſt be as the Cubes of their mean diſtances from the *Sun*: and the Comet becomes viſible only for that part of its Period, wherein it deſcends towards the *Sun*, and approaches near the *Earth* as in F; and then after it hath paſſed its *Perihelion*, conſtantly riſing higher from the *Sun* about G, it will begin to vaniſh, and will not be viſible without a Teleſcope. If the *Aphelion* diſtance be to the *Perihelion*, as 1000 is to one, the Velocity of a Comet in the *Perihelion*, will bear the ſame Proportion to the Velocity at the *Aphelion*. For the Area A S B muſt be but equal to the Area P S D, if the Arches AB and P D be deſcribed by the Comet in equal times, and then the Arch P D muſt be greater than A B, in the ſame Proportion as A S is greater than P S. This is the Proportion of their abſolute Velocities. But their Angular Velocities about the *Sun* are in a duplicat Proportion of theſe diſtances, or as 1000000 to 1, ſo that while the Comet in its *Perihelion* deſcribes one Degree with its Angular Motion; when it aſcends to its *Aphelion*, it will deſcribe in an equal Time but the $\frac{1}{1000000}$ of a Degree; ſo that there it may have ſo ſlow a Motion, that it will require ſeveral Years before it can compleat a Degree of Angular Motion.

The ſmall Portion of the Ellipſe which a Cone deſcribes while it is ſeen by us, may be eſteemed as a Parabola.

SINCE the Elliptick Orbits of Comets are all of them very Excentrick, thoſe Portions of them wherein they become viſible to us, may paſs for Parabola's. For if one of the *Focus*'s of an Ellipſe recede infinitely from the other, this Ellipſe will thereby be changed into a Parabola, as when the two *Foci* come together and coincide, the Ellipſis is changed into a Circle. Now by conſidering that Portion of a Comet's Orbit which is near the *Perihelion*, as a peice of a Parabola near its *Vertex*, the Calculation of their Motions becomes much eaſier; and upon that *Hypotheſis* our moſt Skillful *Aſtronomer* and *Geometer* Dr. *Halley*, has conſtructed and Calculated a Table, by which the Motions of all Comets are eaſily computed, and the Calculations founded on this *Hypotheſis*, do exactly agree with the Obſervations made on them. Dr. *Halley* himſelf having computed the Motions of ſeveral Comets, and compared them with Obſervations made by others, has found there was ſo nice a Correſpondence between them, that the Calculation ſcarce ever differed from the Obſervation above three Minutes. By which Examples it is abundantly manifeſt that this Theory ſatisfies all the Appearances and Motions of Comets, with no leſs exactneſs than the Motions of the *Planets* are accounted for, and foretold from the Theories we have of them, whoſe computed places do ſometimes differ from Obſervations as much as in Comets. And altho' the Motions of Comets are much more unequal than thoſe of the *Planets*, yet this Theory does wonderfully anſwer all their Appearances; and therefore ſince it is built upon the ſame Laws as the Theory of the *Planets*, and the Motions of one governed by the ſame Phyſical Cauſes as they of the other are; and ſince it accurately anſwers all Obſervations of *Aſtronomers*, it cannot but be the true Theory.

Many Comets move from Eaſt *to* Weſt.

ALTHO' all the *Planets* have their proper Motions from *Weſt* to *Eaſt*, yet many Comets have been obſerved to hold on in a contrary Courſe, and have been ſeen to go from *Eaſt* to *Weſt*, with a very great Degree of Velocity. Such was the Courſe of the Comet which *Regiomontanus* obſerved in the Year 1472, that deſcribed 40 Degrees of a great Circle in one Day. Hence we can poſitively conclude that there are no *Vortices*, or Whirle-pools of Fluid matter in the Heavens, which according to the Opinion of ſome *Philoſophers* carry the *Planets* round the *Sun*: for if there were any ſuch Whirle-pools, when the Comets come down and enter within the Region of the *Planets*, they muſt be neceſſarily driven out of their Courſe, by the rapid Motion of the Solar Vortex, as by a mighty Torrent, which near the

Therefore there can be no Vortices.

Earth is of ſuch a force, that it carries it above 20000 Miles in an Hour: and who can think that ſo rapid a Stream would not affect the Comets, and when they have a Motion contrary to its Motion, ſoon deſtroy it: For what can reſiſt ſo violent a Torrent of Fluid matter. Now many Comets have been obſerved who take a Courſe directly contrary to this Stream, and which perform their Motions with the greateſt Freedom and without the leaſt Reſiſtance, juſt after the ſame manner as they would do in a void Space, where there is nothing to withſtand them. But this is plainly repugnant to the Nature of a *Vortex*, for that *Medium* which can put the *Planets* in motion, would without all Queſtion, ſet all other Bodies which Swim in it a going the ſame way. But ſince there is nothing like this obſerved in Comets, we muſt acknowledge that in the Heavens there is no Reſiſtance, and therefore no *Medium* or Fluid, which compared with our Air hath any ſenſible denſity: For our Air gives a very conſiderable Reſiſtance to all Bodies that move in it.

There is no Fluid in the Heavens which has a ſenſible Denſity.

LET not therefore the *Carteſians* and *Leibnitians*, talk to us any more about their *Vortices*; for the Appearances of the Celeſtial Bodies are ſuch, as that we can by no means admit of them; ſo that they who labour to explain the Motions of the Heavens by them, do only amuſe us with trifles and impoſſibilities; and it is to no purpoſe to trouble our ſelves any longer with their Fancies, ſince there is Demonſtration againſt them.

SINCE the Reſiſtance of a *Fluid Medium* ariſes chiefly from its Denſity, it from thence neceſſarily follows that where there is no ſenſible Reſiſtance of the *Medium*, there the *Medium* muſt have no ſenſible Denſity; and therefore ſince in the Heavens the Comets ſuffer no ſenſible Reſiſtance, but exert their Motions with the greateſt freedom, as if they were in a perfect void or *Vacuum*, there likewiſe the Denſity of the *Medium* muſt be the leaſt that can be, or next to Nothing. And who knows but the *Medium* in the Heavens may be ſo rare and fine, that if you except the *Planets* and their *Atmoſphers,* the matter which is diffuſed thro' all the reſt of the Planetary Region, or our Solar Syſtem, may not be ſo much as that which is contained in an Inch of our common Air. For this we have demonſtrated to be poſſible in our Phyſical Lectures.

A Vacuum or Void is proved.

THE *Philoſophers* after this need trouble us no longer with their Metaphyſical Quirks againſt a *Vacuum*; for they ſeem to be very like the Quibles of the Antient *Sophiſts* againſt the poſſibility of Motion: and as *Diogenes* confuted thoſe *Sophiſts* by riſing and walking, ſo we may anſwer the *Carteſians* by bidding them look up into the Heavens, and there notwithſtanding their nice and ſubtle Arguments, they will find, from the Appearances and Motions there obſerved, a manifeſt Demonſtration for the neceſſity of a *Vacuum.*

The Tails of Comets.

FEW Comets have been obſerved before their deſcent to the *Sun,* and their Return from their *Perihelion.* For before they have been conſiderably heated in the Neighbourhood of the *Sun,* they ſcarcely project a Tail to make them remarkable. But after they have been well heated in their *Perihelion,* then they generally ſend forth a large ſhining and fiery Tail, which ſeems to conſiſt of a very fine, rare and luminous matter, which is attenuated by the great heat of the *Sun,* and projected with an immence force from the Body of the Comet. The cauſe of this Projection perhaps may be very like that whereby a great quantity of fine Lucid Vapour was lately thrown out from the *Earth,* to an immenſe height above the Air, ſo that it was viſible thro' the greateſt part of *Europe*; and in Figure and Luſtre looked very like the Tails of Comets, but the matter being ſpent it ſoon vaniſhed.

The Tails of Comets always oppoſite to the Sun.

IT is very remarkable that all Comets have their Tails in oppoſition to the *Sun,* that is if the *Sun* be in the *Weſt,* the Tail is projected *Eaſtward,* or if the *Sun* be in the *Eaſt,* the Tail looks *Weſtward*; at Midnight the direction of the Tail is to the

Lecture XVII. the *North.* Theſe Tails grow bigger as they deſcend to the *Sun*, and at the *Perihelions* they are biggeſt; and as they go further off from the *Sun*, and cool by degrees, the Tail leſſens, till at laſt it is contracted within the Comets Atmoſphere.

COMETS which have ſhort Tails do not throw forth the matter of them with a very quick Motion, in a continual Stream from their Bodies, for then they would ſoon be diſſipated and vaniſh; but theſe Tails ſeem to be rather permanent and fixed Columns of Vapour and Exhalations, which being propagated from the Body with a ſlow Motion upwards, and retaining ſtill the Motion which they had impreſſed in them to go along with the Comet, they ſtill continue to move on with the Body thro' the Celeſtial Regions. From hence we may likewiſe conclude that in the Heavens there is no Reſiſtance; for in them not only the Solid Bodies of *Planets* move, but alſo the thin and fine Vapours which ariſe from Comets feel no reſiſtance, but move with the greateſt freedom, and for a long time preſerve their Motions.

THE great Comet which appeared in the Year 1680, after its departure from the *Perihelion,* projected ſuch a Tail as extended its ſelf more than 40 Degrees in the Heavens; nor can this be a wonder, for it was ſo near the *Sun,* that its diſtance from his Surface at the *Perihelion,* was but a ſixth Part of the Diameter of the *Sun's* Body; and therefore the *Sun* ſeen from the Body of the Comet would appear to fill the greateſt part of the Heaven, and its Apparent Diameter would not be leſs than 120 Degrees; and therefore the heat it received from thence muſt be prodigiouſly intenſe beyond imagination, for it exceeded above 3000 times the Heat of red hot Iron. And therefore we muſt allow that the Bodies of Comets which can bear ſo great a heat muſt be very denſe, hard and durable Bodies: for if they were nothing but Vapours and Exhalations raiſed from the *Earth* and *Planets,* as ſome have dreamt, this

Comet, at ſo near an approach to the *Sun*, muſt have been quite deſtroyed and diſſipated.

LECTURE XVIII.

The Spherical Doctrine, or of the Circles of the Sphere.

SINCE every Spectator in whatever place of the vaſt Expanſion of the Univerſe he reſides, is always in the Center of his own view, when he looks up at the Heavens, he will ſee it as a Concave Spherical Surface, whoſe Center is the Eye, which Surface is every where beſpangled with an innumerable multitude of ſhining *Stars*: and the Spectator will likewiſe obſerve that all the Heavenly Bodies perform their Motions whither real or apparent in this Surface. Now ſince the diſtance of the *Earth* from the *Sun* is but a Point, as it were, in compariſon of the immenſe diſtance of the *Starry* Firmament, in whatever Point of its Orbit the *Earth* is placed, there will be the ſame proſpect of the Heavens, the ſame Poſition and Magnitude of the *Stars* and Figures of the Conſtellations, as a Spectator would obſerve did he reſide in the *Sun*, and therefore it is the ſame thing as to theſe Appearances whither the Center of the Univerſe or Heavens, be placed in the *Sun* or *Earth*: and if we imagine ſeveral Circles to paſs thro' the *Earth*, and to have its Center for theirs, and others Parallel to them to paſs thro' the *Sun*, the Circles in the Heavens will ſeem to coincide, becauſe their diſtance will vaniſh in reſpect of the immenſe diſtance of the *fixed Stars*; and thoſe Circles which are drawn thro' the *Sun* and *Earth* on Parallel

The Eye of a Spectator is always in the Center of his own View.

It is no matter whither the Center of the Heavens be conſidered to be in the Sun *or* Earth.

Parallel Planes will appear to paſs thro' the ſame *Stars* in the Heavens.

A great Circle.

FOR the better determining the places of all ſort of *Stars* and obſerving of their Motions, it is requiſite to imagine ſeveral Circles deſcribed in the Heavens, ſome of which are great Circles, others of a leſs ſize. A great Circle is the greateſt that can be deſcribed on the Surface of the Sphere, and divides it into two equal portions, and has likewiſe the ſame Center that the Sphere has, and therefore all great Circles having the ſame Center muſt cut each other into equal Portions or Semicircles.

The leſſer Circles.

THE leſſer Circles divide the Sphere into unequal Portions, and have not the ſame Center that the Sphere has; and they take their Denomination from ſome great Circle to whom they are Parallel, as the Equator, Horizon, or Ecliptick.

The Poles *of Circles.*

EVERY Circle of the Sphere hath two *Poles*, which are Points on the Surface of the Sphere, which are at equal diſtances from all the Points of the Circle; and they are placed in the Surface where a Line from the Center perpendicular to the Plane of the Circle meets with the Surface of the Sphere, when the Line is produced both ways.

Circles moveable and immoveable.

SOME Circles of the Sphere depend only upon the place of the Spectator, and have a regard to his poſition; others again are produced by Motion: the firſt are called moveable Circles, becauſe as the place of the Spectator is changed ſo are they, and move along with him. The ſecond are called immoveable, and are ſuppoſed to be fixed to the ſame Points of the Heavens.

THE Circles which owe their Origin to Motion, are chiefly the Ecliptick and Equinoctial and their Parallels. For becauſe the *Earth* is carried round the *Sun* in a Year, a Spectator in the *Sun* will ſee the *Earth* deſcribe a great Circle in the Heavens or *Starry* Firmament, which we call the Ecliptick; and it is the very ſame Circle which we in

The Ecliptick and its parts.

Earth obſerve the *Sun* to move in by an Apparent Motion, likewiſe in the ſpace of a Year, as we ſhewed before: The Ecliptick is divided into Twelve equal parts, which are called the Twelve Houſes or Signs, and they have their Names from the Neighbouring Conſtellations: they begin at the Vernal Interſection of the Equator and Ecliptick, and are reckoned from the *Weſt Eaſtwards* as the *Sun* ſeems to move. The firſt three Signs are ♈ ♉ ♊, which riſe from the Æquinoctial, and aſcend *Northwards* to the Point of the Summer Solſtice. The next three are ♋ ♌ ♍, which begin from *Cancer* and deſcend again towards the Equinoctial till they come to the Autumnal Interſection. The third Ternary of Signs conſiſts of ♎ ♏ ♐, which begin at *Libra*, and departing from the Equinoctial *Southward*, reach the Winter Solſtice. ♑ ♒ ♓ make the fourth, which begin at *Capricorn*, and end in the Vernal Equinox. Each Sign is divided into 30 Degrees and conſequently the whole Ecliptick into 360. The *Sun* is always obſerved in this Circle and never deviates in the leaſt from it, as the *Planets* do, which go ſometimes on one ſide of it, ſometimes on the other, thro' a ſpace of about eight Degrees, and therefore if we imagine a broad Circle or Zone, of about Sixteen Degrees in breadth, which the Ecliptick cuts in the middle, this will be the Space wherein the *Planets* perform all their Motions, and by the *Greeks* it is called the *Zodiack*, by the *Latines Signifer*, or the Sign bearer, becauſe of the Signs placed within it.

The Zodiack.

Secundaries of the Ecliptick.

IF we imagine an indefinite number of great Circles to be drawn thro' the *Poles* of the Ecliptick and interſecting of it, theſe Circles are called Secundaries of the Ecliptick; for by them every *Star* and Point of the Heavens are reduced to the Ecliptick, and have their places in regard to it determined in the Heavens. For the Place of any *Star* reduced to the Ecliptick is that Point where the Secundary paſſing thro' the *Star* interſects the Ecliptick: The Arch between this Point and the beginning of ♈ or the Vernal interſection, and counted

Eaſtward is called the Longitude of that *Star*, as the Arch of the Secundary between the *Star* and the Ecliptick is called the Latitude of that *Star*, and is either *North* or *South*; for the Ecliptick divides the *Starry* Firmament into two *Hemiſpheres North* and *South*.

The Longitude of a Star.

SINCE the *Earth* turns round its own *Axis*, from thence it comes, that the Inhabitants thereof ſee the Heavens and all the *Stars* revolve round the *Earth* in the Space of twenty four Hours from *Eaſt* to *Weſt*; which Apparent Motion is called the Diurnal, or daily Revolution of the Heavens, and was conceived to be by the Force of a moving Sphere called the *Primum Mobile* or firſt mover, which carried the whole Heavens round with it about an *Axis* which coincides with the *Axis* of the *Earth* produced, as if the *Earth* it ſelf had no Motion, but the Heavens were Volvible. The great Circle which is exactly between the two *Poles* of the *Earth*, or at equal diſtance from both, is called the *Earth*'s Equator; and if we imagine the Plane of this Circle extended or produced to the Heavens, it will there make the Celeſtial Equinoctial Circle, or the Equator in the Heavens; and all the *Stars* and every Point of the Heavens, except the two *Poles*, will ſeem to deſcribe by their Apparent Revolution either this Circle, or a leſſer Parallel to it; which Circles are either bigger or leſſer, according as the *Stars* which ſeem to deſcribe them, are more removed or nearer to the *Poles*.

The Primum mobile.

The Equinoctial.

THE Equinoctial and Ecliptick being both great Circles, will cut each other into Semi-circles, and their common interſection will always keep Parallel to its ſelf, and will conſtantly be directed to the ſame Point of the Heavens, for we here abſtract and conſider as nothing, that very ſmall Motion whereby the *Axis* of the *Earth* falls backward, and this Interſection equally with it. And therefore whenever the *Sun* is obſerved in the Point of the Ecliptick where this interſection is, that is, when the *Earth* is really in the oppoſite, the *Sun* then by his Apparent diurnal Motion will deſcribe the Equinoctial Circle in the Heavens; and there being two Points of Interſection, the *Sun* will be obſerved to revolve in the Equinoctial twice* every Year, that is, when he is in the two Interſections, Vernal and Autumnal, at which times all the Inhabitants of the *Earth* will have their Days and Nights equal; upon which account this Circle has got the Name of the Equinoctial. The Angle which the Ecliptick and the Equator make at the Points of Interſection is about 23½ Degrees. The *Sun* leaving theſe Interſections by an Apparent Motion, declines every Day from the Equinoctial Circle more and more towards the *North* or *South*, till he comes to the Nintieth Degree from the Interſections, where he appears to be 23½ Degrees diſtant from the Equinoctial, which is his greateſt Declination: For from thence he begins to return again towards the Equinoctial, and therefore the two leſſer Circles, which the *Sun* at his greateſt Declination ſeems by his Diurnal Motion to deſcribe, are called the *Tropicks*, from a Greek Word which ſignifies to return: This upon the *North* ſide of the Equinoctial is called the *Tropick* of *Cancer*, the other on the *South* ſide the *Tropick* of *Capricorn*. How this Apparent Motion of the *Sun* and conſtant change of his Declination ariſe from the real Motion of the *Earth*, the *Sun* himſelf being all the while at reſt, we have already explained in our ſeventh *Lecture*.

The two Tropicks.

The two Polar Circles

THERE are two remarkable leſſer Circles of the Sphere which are Parallel to the Equinoctial; and theſe are deſcribed by the Apparent Diurnal Motions of the two *Poles* of the Ecliptick round the *Poles* of the Equinoctial, from which they are diſtant 23½ Degrees. They are called the two Polar Circles; this in the *Northern* Sphere is named the *Arctick* Circle, from the two *Bears* which lye near it; the other Circle on the *South* is called the *Antarctick* or Circle oppoſite to the *Arctick*.

IF thro' the *Poles* of the World, or of the Equinoctial, there be conceived innumerable great Circles to be drawn, they are called Secon-

Secondaries of the Equinoctial.

daries of the Equinoctial, by the help of which the Poſition of every Point of the Heavens, in regard to the Equinoctial, is determined, as before they were determined by the Secondaries of the Ecliptick in regard to the Ecliptick: And the right Aſcenſion of a *Star* or Point in the Heavens is an Arch of the Equinoctial, between the beginning of *Aries* and the Point where the Secondary paſſing thro' the *Star* cuts the Equinoctial. The Declination of a *Star* or Point is the Arch of the Secondary intercepted between the *Star* and the Equinoctial, which is likewiſe as the Latitude either *North* or *South*, as the *Star* declines towards the *North* or *South Pole*: From hence theſe Secondaries are called Circles of Declination. And the two chief of them are the two Colures, one of which paſſing thro' the two Equinoctial Interſections is called the Equinoctial Colure; and the other, which cuts the former at right Angles and paſſes thro' the *Poles* of the Ecliptick, is called the Solſtitial Colure, becauſe it interſects the Ecliptick in the Points which are at the greateſt diſtance from the Equator; to which when the *Sun* comes, he does not ſenſibly for ſome Days change his Declination, but ſeems to ſtand without approaching to, or receding from the Equinoctial, and therefore theſe Points are called Solſtices.

The Right Aſcenſion of a Star.

The two Colures.

THAT Circle which is on the Surface of the *Earth* exactly in the middle between the two *Poles* is the *Earth*'s Equator, and by the production of it we ſhewed that the Celeſtial Equinoctial was formed. And as the places of all the *Stars* in the Heavens are determined by their Longitude and Latitude in regard to the Ecliptick and its Secondaries; ſo by the Terreſtial Equator and its Secondaries drawn thro' the *Poles* of the *Earth*, the Poſition of Cities and Places upon the Surface of the *Earth* are determined according to Longitude and Latitude. A Secondary of the Equator paſſing thro' any place on the *Earth*'s Surface is called the Meridian of that place; becauſe, that when by the Rotation of the *Earth* round its *Axis* the Plane

The Longitudes and Latitudes of Places.

of that Meridian comes to paſs thro' the *Sun*, then the Inhabitants under this Meridian have Midday. The Longitude of any City or Place is an Arch of the Equator intercepted between a certain Point where ſome fixed Meridian paſſes, which is called the firſt Meridian, and the Meridian of the Place. The Antient *Geographers* made the firſt Meridian paſs thro' ſome known place which was as far *Weſtward* as they knew, and from thence they reckoned the Longitude of all places conſtantly *Eaſtward*: But ſince by Navigation it has been diſcovered, that there is no place in the *Earth* that can be eſteemed the moſt *Weſterly*, ſo that there is not another more *Weſtward* beyond it, this way of computing the Longitude from a firſt Meridian hath been generally layed aſide, and now each *Geographer* determines the Longitudes of places in regard to the Longitude of the chief City of the Country where he dwells. The Latitude of a Place is an Arch of the Meridian of that place intercepted between the Place and the Equator, and is either *North* or *South*, as the place lyes on the *North* or *South* ſide of the Equator.

The Periœci.

OF the Inhabitants of the *Earth* compared with one another, in regard to their Meridians and Parallels, ſome are called *Periœci*, that live under the ſame Parallel, but in the oppoſite Semicircles of the ſame Meridian; both of them have the Seaſons of the Year the ſame, the *Sun* by its Annual Apparent Motion coming to or receding from the Vertex of both Places at the ſame time of the Year; but they change their turns of Night and Day, ſo that when it is Midday to the one, it is Midnight to the other. Others again are called *Antœci*, whoſe Habitations lye in the ſame Semicircle of the Meridian, but in oppoſite Parallels, and both of them have Midday and Midnight at the ſame inſtant of time; but the Seaſons of the Year are different, it being Summer to one when it is Winter to the other. Laſtly, there are the *Antipodes*, whoſe Habitations being ſituated in both oppoſite Parallels and oppoſite Meridians, have their Feet

The Antœci.

The Antipodes.

directly oppoſite to one another in a Line paſſing thro' the Center of the *Earth*; and they have not only their Days and Nights directly contrary, but alſo the Seaſons of the Year: When it is Summer in the one, it is Winter in the other place, and when Midday in the firſt, the ſecond reckons Midnight.

The five Zones.

THE four leſſer Circles in the Surface of the *Earth's* Globe, which lye directly under the Circles of the ſame name in the Heavens, *viz*, the two *Tropicks* and *Polars*, divide the *Earth* into five Portions which are called *Zones*; of which the Torrid is that which is bounded on each ſide by a *Tropick*, and was believed by the Antients to be not Habitable by reaſon of the violent Heats: But our Modern Travellers and Voyagers have diſcover'd this Tract of the *Earth's* Surface to be the moſt fruitful and delightful of all, abounding not only with the things that are neceſſary, but ſuch likewiſe as conduce to the ſatisfaction and pleaſure of Life; upon which account it is very well ſtored with Inhabitants. There are two cold *Zones* which the Polar Circles comprehend; in the middle of the one lyes the *Arctick Pole*, of the other the *Antarctick*, and in them the cold is ſo exceſſive that they are ſcarcely habitable. Beſides theſe, between the Frigid and the Torrid *Zone*, on each hand lye the two Temperate ones, that on the *North* is poſſeſſed by us, the other our *Antipodes* keep. *Virgil* elegantly deſcribes theſe five *Zones*.

Quinq; tenent Cælum Zonæ, *quarum una coruſco*
Semper Sole rubens & Torrida ſemper ab igne;
Quam circum extremæ dextra lævaq; trahuntur,
Cærulea glacie concertæ atq; imbribus atris.
Has inter mediamq; duæ mortalibus ægris
Munere conceſſæ Divûm.

The Amphiſcij.

THE Inhabitants of the Torrid *Zone* are called *Amphiſcii*, having their Meridian Shadows at different times of the Year projected towards both *Poles*; but when the *Sun* comes to be Vertical to them, then they have no ſhadow, and are *Aſcii* or Shadowleſs, nothing that ſtands perpendicularly upwards having a Shadow at Noon. We who live in the Temperate *Zones* may be named *Hetroceii*, having our Meridian ſhadow projected only towards one *Pole* thro'out the whole Year. But the miſerable People of the two Frigid *Zones* are called *Periſcii*, becauſe the *Sun* not ſetting upon them, their Shadow turns quite round in the Space of twenty four Hours.

The Aſcii.

The Periſcii.

THE two Circles which we conceive to be immoveable, and determined by their reſpect to the Spectator, are the *Horizon* and Meridian. The *Horizon* is that great Circle which any one when he is placed in a large extended Plane, or in the open Sea obſerves, terminating or bounding his Sight every where round him, by which the viſible Heaven is diſtinguiſhed and ſeparated from the inviſible. This *Horizon* being diſcovered by our Senſes is called the ſenſible *Horizon*, from which the Rational *Horizon* Parallel to it is diſtant by the Semidiameter of the *Earth*, through whoſe Center it paſſes: For the *Aſtronomers* reduce the Appearances of the Heavens to a Spherical Surface, which is not concentrical to the Eye but to the *Earth*.

The Horizon *ſenſible and Rational.*

'TIS true, theſe two *Horizons*, produced to the *fixed Stars*, will appear to coincide into one, ſince the *Earth* compared to the Sphere in which the *fixed Stars* appear is but a Point; and therefore the two Circles which are but a Point diſtant from each other, may be well conſidered as coinciding into one. There are two *Poles* of the *Horizon*, the one is the Point of the Heavens which is directly over the Head of the Spectator, and is called the *Zenith*; the other directly oppoſite under his Feet is named the *Nadir*; and innumerable Circles drawn thro' theſe *Poles* to the *Horizon* are ſtiled *Vertical Circles* or *Azimuths*. Among them there are two particularly remarkable, one of which is the Meridian, and the other is the *Prime Vertical*; the firſt paſſes thro' the *Poles* of the E-

Zenith *and* Nadir, *the* Poles *of the* Horizon.

quator and the *Zenith*, and cuts the *Horizon* in the Points of *North* and *South*; the other paſſing thro' the *Zenith* cuts the former at right Angles, and marks upon the *Horizon* the Points of *Eaſt* and *Weſt*. Theſe Circles divide the *Horizon*, at their Interſections with it, into four Quarters, each of which is again ſubdivided into eight Parts, and conſequently the whole *Horizon* is divided into Thirty two Parts, which are called the *Rhumbs* or Points of the Compaſs.

The Vertical *or* Azimuth *Circles.*

The Altitude or Depreſſion of a Star.

THE Altitude or Depreſſion of any *Star*, is an Arch of the Vertical intercepted between the *Horizon* and the *Star*.

AGAIN, the *Azimuth* of a *Star* is an Arch of the *Horizon*, intercepted between the Points of *North* and *South* and the Point where the Vertical paſſing thro' the *Star* cuts the *Horizon*, and is either *Eaſterly* or *Weſterly*. The riſing or ſetting Amplitude of a *Star* is an Arch of the *Horizon* intercepted between the points where the *Star* riſeth or ſetteth and the points of *Eaſt* and *Weſt*; and this Amplitude is either *North* or *South*, according as the *Star* at riſing or ſetting is to the *North* or *South* of thoſe Points.

The Amplitude.

AS in the *Horizon* all the *Stars* firſt appear and diſappear, ſo in the Meridian Circle they all ariſe to their greateſt height or Altitude, where they are ſaid to *Culminate*: ſo likewiſe they are at their greateſt depreſſion below the *Horizon* when they arrive at the ſame Meridian. Now ſince the Meridian makes Right Angles both with the Equator and *Horizon*, it will divide the Segments of the Equator and all its Parallels, as well thoſe that lye above the *Horizon* as thoſe which are below it, into equal Portions; and therefore the time between the riſing of a *Star* and its Culmination or arrival at the Meridian, will be equal to the time between this Culmination and its ſetting; and becauſe the *Sun* every Day deſcribes ſome Parallel by its apparent Diurnal Motion, when the *Sun* comes to the Meridian at any time it will be then Midday, and Midnight when he arrives at the ſame Meridian below the *Horizon*, and from thence this Circle has its Name. The

The Culmination.

Nintieth or *Nonageſimal Degree* is that Point of the Ecliptick which is 90 Degrees diſtant from the Interſections of the *Horizon* and Ecliptick, and the Altitude of this Point is the meaſure of the Angle of the *Horizon* and Ecliptick. The *Medium Cœli* or Midhaven, is that Point of the Ecliptick which culminates, or is in the Meridian. In the Aſcending Signs from ♑ to ♋, the *Nonageſimal* Degree is to the *Eaſt* of the Meridian, but in the Deſcending Signs from ♋ to ♑, the *Nonageſimal* lyes *Weſtward* of the Meridian.

The Horizon and Meridian truly moveable Circles.

ALTHO' we have here conſidered the *Horizon* and Meridian as immoveable Circles, taking the Apparent Motion of the Heavens as real; yet if we ſpeak according to truth and the nature of things, the *Horizon* and Meridian are the only moveable Circles, and the *Sun* or a *Star* riſes not when it aſcends, but when the Plane of the *Horizon* deſcends below it, ſo that the *Star* or *Sun* becomes viſible. So likewiſe the *Stars* ſet not by their own Motion or going down under the *Horizon*, but by the *Horizon*'s aſcending and getting above them; which Motion of the *Horizon* ariſeth from the Rotation of the *Earth*. So alſo the *Sun* or *Stars* arrive at the Meridian when the Plane of the Meridian of any place, having an Angular Motion round the *Axis* of the *Earth*, comes to paſs thro' the Bodies of the *Sun* or *Stars*.

The Univerſal Meridian.

SINCE every Meridian finiſhes its circulation round the *Axis*, or 360 Degrees in Twenty four Hours, it muſt each Hour have an Angular Motion of 15 Degrees, which is the Twenty fourth Part of 360; and therefore if we conceive a Circle paſſing thro' the *Poles*, which makes an Angle of 15 Degrees with the Univerſal Meridian paſſing thro' the *Sun*, when by the *Earth*'s Rotation the Plane of the Meridian of any Place comes to the Plane of this Circle after it has paſſed the Univerſal Meridian, then the Inhabitants in that Meridian will reckon one Hour after Midday, and therefore that Circle is called the Circle of the firſt Hour. In like manner, if another Circle be conceived cutting the Equinoctial in the Thirtieth

Lecture XVIII. Degree from the Univerſal Meridian, this will be the Circle of the ſecond Hour; and when the Plane of the Meridian of the Place comes to coincide with it, it will be in that Place two of the Clock in the Afternoon. After the ſame manner, if thro' the *Poles* and every 15 Degrees of the Equator we conceive Circles to paſs, they are called *Horary* Circles, and they will divide the Equinoctial into Twenty four equal parts, and each of them in its order will determine the Hour that is to be reckoned in a Place, when the Plane of the Meridian of that Place comes to coincide with that Circle. So for Example, when the Meridian of the Place comes to the Circle which makes 75 Degrees with the Univerſal Meridian, the Hour then counted in that place will be the fifth from Noon. But when the Meridian of the Place makes an Angle of 90 Degrees with the Meridian paſſing thro' the *Sun*, then it will be the ſixth Hour. But on the other hand, if we ſhould imagine the Meridian of the Place to be immoveable, and that a Circle paſſing thro' the *Poles* and the *Sun* ſhould together with the *Sun* turn round the *Axis*, as it appears to do; when the Plane of this Circle in which the *Sun* reſides coincides with a Circle that makes an Angle of 15 Degrees with the Meridian of the Place *Weſtward*, it is then the firſt Hour after Midday; and the Circle with which the Circle paſſing thro' the *Sun* and *Poles* does then coincide, is called the Circle of the firſt Hour: The next Circle to this, which makes an Angle of 30 Degrees with the Meridian of the Place, is the *Horary* Circle for Two of the Clock, and that which makes an Angle of 45 Degrees with the Meridian of the Place, is the *Horary* Circle for Three of the Clock &c.

The Horary Circles.

Plate XVI. Fig. 4.

IN any Place of the Terraqueous Globe the Height of the *Pole* above the *Horizon* is equal to the Latitude of the Place. Let the Circle H Z Q be the Meridian, H O the *Horizon*, ÆCQ the Equator, Z the *Zenith*, and P the *Pole*: the

Elevation of the *Pole*, or its Diſtance from the *Horizon*, is the Arch P O, the Latitude of the Place or its diſtance from the Equator is Z Æ. And becauſe the Arch P Æ between the *Pole* and the Equator is a Quadrant, or fourth Part of a Circle, and the Arch Z O from the *Zenith* to the *Horizon* is likewiſe a Quadrant, theſe two Arches Z Æ and P O muſt be equal. Take away the Arch Z P which is common to both, and there will remain the Arch Z Æ equal to the Arch P O, that is, the Latitude of the Place is equal to the Altitude or height of the *Pole* above the *Horizon*.

The height of the Pole *above the* Horizon *is always equal to the Latitude of the Place.*

HENCE we have a Method of meaſuring the Circumference of the whole *Earth*, and of knowing how many Miles it is round the *Earth*: For if we go directly *Northward* till the *Pole* be Elevated one Degree higher, and then if we meaſure the length of the way we have gone *Northward*, and have the number of Miles it contains, we ſhall have the number of Miles in a Degree of a great Circle of the *Earth*'s Globe; and this number multiplied by 360, the Degrees in the whole Periphery, it will give the length of the Circumference of the *Earth* in Miles. By the moſt accurate Obſervations, the Length of a Degree is found to be 69 Engliſh Miles, which was commonly reputed to be only 60 Miles.

LECTURE XIX.

Of the Doctrine of the Sphere.

The Right Poſition *of the* Sphere.

Plate XVI. Fig. 5.

An oblique Sphere; *or an* oblique Poſition of the Sphere.

Fig. 6.

THE Angle contained between the Equator and the Horizon, is meaſur'd by the Arch of the Meridian Æ H, which is the Complement of the Latitude to a Quadrant. And therefore if that Angle be right, the Latitude of the place will be nothing, or the place will be in the Equator; or the Equinoctial Circle will paſs thro' the Vertex of the place, and all the Parallels of the Equator will be perpendicular to the Horizon; And therefore this Poſition of the *Sphere* is call'd a *Right Poſition,* in which all theſe Parallels are cut by the *Horizon* into equal Portions, whence the Stars are as long above the *Horizon* as they lye hid under it: Here likewiſe the Poles lye in the Horizon without any Elevation, as is manifeſt by the Figure, where the Point of the Equinoctial Æ is in the Vertex, and the Poles P, *p* in the Horizon. If we go from the Equator towards either of the Poles, the Equator will then appear to depart from the Vertex or Zenith, and to come nearer to the Horizon, making with it an oblique Angle; whence ſuch a Situation is called an *oblique Poſition of the Sphere,* and the Pole towards which we move doth riſe more and more above the Horizon the nearer we approach it. Its Elevation being always equal to the Latitude of the Place, while the other continues as much depreſſed below it. The Figure does clearly ſhew this ſort of Poſition which we and all that live in the temperate Zones obtain, where the Equator Æ Q is biſected by the Horizon, as it is in a right

Sphere; wherefore when the Sun, by his apparent Diurnal Motion, deſcribes this Circle, it makes the Day equal to the Night: But the Parallels of the Equator, in this *Oblique Poſition* are not cut into two equal Parts by the Horizon; but thoſe which are towards the elevated Pole, each of them have a greater Portion above than under the Horizon: And as each Parallel is nearer the Pole, ſo much the larger Portion of it ſtands above the Horizon. But when the diſtance of the Parallel from the Pole becomes leſs than the Elevation of the Pole or the Latitude of the Place, then that Parallel, and all thoſe included within it, are wholly above the Horizon, no part of them ever ſetting under it. The contrary happens in the Parallels which lye towards the depreſs'd Pole, a ſmaller Portion of them being above the Horizon, and the greater part lying under it. And thoſe Parallels which are nearer to the depreſſed Pole than the Latitude of the Place, remain perpetually, together with the Stars included within them, under the Horizon, and are never viſible to us. Hence it is neceſſary, ſince the Sun each Day deſcribes by his apparent Diurnal Motion ſome Parallel, that from the Vernal Equinox to the Summer Solſtice, the Days growing longer and longer, will be continually longer than the Nights; After the Solſtice, tho' the Days continue till the Autumnal Equinox to be longer than the Nights, yet they become ſhorter and ſhorter, and at the Equinox they but juſt equal the Nights: From thence to the Winter Solſtice the Days continually become ſhorter than the Nights, and are the ſhorteſt when the Sun is in that Solſtice; but as the Sun leaves it they increaſe again, and in the Vernal Equinox the Day is as long as the Night.

IN an *Oblique Sphere* the Stars all obliquely riſe and ſet. And as the *Right-Aſcenſion* of a Star is the Arch of the Equator contained between the firſt of *Aries* and that Point which comes to the *Meridian* with the Star, or that Point which in a *Right Sphere* riſes with the Star. So the Oblique

Aſcenſion is the Arch of the Equator between the firſt of *Aries* and that Point of the Equator which riſes together with the Star in an *Oblique Sphere*, and numbered from *Weſt to Eaſt*, which according to the Obliquity of the *Sphere* is various. The Difference between the Right and the oblique Aſcenſion is called the *Aſcenſional Difference*.

IN an *Oblique Sphere* there is one Parallel as much diſtant from the elevated Pole, as the Place is from the Equator, which is called the Circle of *Perpetual Apparition*, or the biggeſt of all thoſe which conſtantly appear, which is ſuch, that all Stars incloſed within it never either riſe or ſett; tho' they ſometimes riſe higher, ſometimes deſcend lower towards the Horizon. Towards the other Pole there is another Circle oppoſite to this, which is the Circle of *Perpetual Occultation*, within which all the Stars that are contained never riſe, but conſtantly lye hid under the *Horizon*, and ſo are not to be ſeen.

A Parallel Sphere.

Plate XVI. Fig. 7.

IF the Equator makes no Angle with the Horizon, but thoſe two Circles coincide; In ſuch a Situation the Pole and Vertex coincide, and all the Parallels of the Equator become Parallels to the Horizon; And ſuch a Situation is call'd a *Parallel Sphere*, in which no fixed Stars do ever either riſe or ſett, but turn round in Circles Parallel to the Horizon. And when the Sun enters the Equinoctial, it then glides the whole Day along the Horizon. When he riſes towards the elevated Pole he never ſetts, but makes a very long Day of ſix Months: But when he goes from the Equinoctial towards the depreſſed Pole, he never riſes, and then there is a conſtant Night of ſix Months length. This Poſition of the *Sphere* belongs only to them who live at the Pole, if any are ſo miſerable as to have ſuch a place for their Habitation.

Climates and Parallels.

THE antient Geographers divided the *Earth* by Climates and Parallels; for they who live under the Equinoctial, being in a Right *Sphere*, have their Days and Nights equal: If we remove from thence towards either Pole, the Days in Summer become longer than the Nights, and the nearer we approach the Pole, the greater is the Difference between Day and Night, when the Day is at the longeſt; till we come under the Polar Circles, where there is no Night at all. Hence the Geographers did ſo divide the Earth by ſuch Parallels as made the longeſt Day encreaſe by quarters of an Hour; that is, each Parallel was ſo far diſtant from the next, that the longeſt Day in the more remote from the Equator, was a quarter of an Hour longer than that Day at the Parallel nearer to the Equator: And therefore reckoning the Equator as the firſt Parallel, the ſecond Parallel paſſed thro' thoſe Parts of the Earth, where the longeſt Day was twelve Hours and a quarter long. Under the third Parallel the longeſt Day was twelve Hours and two Quarters. In the fourth, the longeſt Day was twelve Hours and three quarters, &c. Now two ſuch Parallels made up a Climate, which were therefore diſtinguiſhed by the longeſt Day encreaſing half an Hour from the one to the other. Now the Exceſs of the Solſtitial Day above twelve Hours may grow ſtill bigger, till we come to the Polar Circle, where the Sun not ſetting makes the Day twenty-four Hours long, which is greater than the Equinoctial Day of twelve Hours by twenty-four half Hours, or forty-eight quarters of an Hour. From hence we gather that the number of Climates between the Equator and Polar Circle muſt be twenty-four, and the number of the Parallels forty-eight.

The riſing and ſetting of the Stars Coſmical, Acronycal, and Heliacal.

Becauſe the Civil Year of the Antients did not keep pace or agree with the apparent annual Motion of the Sun; having the Day of the Month, and the Year when any memorable Action fell out, it could not be from thence immediately known in what Seaſon of the Year it was done. And therefore when the Husbandmen ſettled the Times for the ſeveral diſtinct parts of their Buſineſs, they could not point out that Time by a certain Day of their *Kalendar*; for the ſame

Lecture XIX. Day of the Month was not always in the ſame Seaſon of the Year, but it was neceſſary to have more certain Characters and marks to diſtinguiſh Times; and therefore the Writers of Husbandry, Hiſtorians and Poets had recourſe to the riſings and ſettings of the *Stars*, by them to mark out the Times. And of theſe riſings and ſettings they reckoned three ſorts *viz.* The *Coſmical*, *Acronychal* and *Heliacal.* A *Star* is ſaid to riſe or ſett *Coſmically* which riſes or ſetts when the *Sun* riſes; ſo that a *Star* which riſes or ſetts in the Morning riſes or ſetts *Coſmically.* A *Star* riſes *Acronychally* when it riſes while the *Sun* ſetts, that is in the Evening when it is in Oppoſition to the *Sun*, and is viſible all Night.

A *Star* riſes *Heliacally*, when after it has been in Conjunction with the *Sun*, and on that account inviſible, it comes to be at ſuch a diſtance from him, as to be ſeen in the Morning before *Sun* riſing, when the *Sun* by his Apparent Motion recedes from the *Star* towards the *Eaſt.* But the *Heliacal* ſetting is when the *Sun* approaches ſo near a *Star* that it hides it with his Beams, which keep the fainter light of the *Star* from being perceived. And therefore the *Heliacal* riſing and ſetting is rather an Apparition and Occultation than a riſing and ſetting.

ALL the *fixed Stars* in the *Zodiack*, as likewiſe the Superiour Planets *Mars*, *Jupiter* and *Saturn* riſe *Heliacally* in the Morning a little before *Sun* riſing, and a few Days after they have ſett *Coſmically*; becauſe the *Sun* in his Apparent Motion gets before them, moving faſter *Eaſtward*: But they ſet *Heliacally* in the Evening a little before their *Acronychal* ſetting. But the *Moon* whoſe Motion *Eaſtward* is always quicker than the Apparent Motion of the *Sun*, riſes *Heliacally* in the Evening, after the new *Moon* or the Change, when it can be firſt diſcovered at *Sun* ſetting; but the *Moon* ſetts *Heliacally* in the Morning when the *Moon* is old and approaching to a Change. The Inferiour *Planets Venus* and *Mercury*, which ſometimes

times ſeem to go *Weſtward* from the *Sun*, and ſometimes again have a quicker Motion than he *Eaſtward*, riſe *Heliacally* in the Morning when they are Retrograde; but when they are direct in their Motions they riſe *Heliacally* in the Evening.

How to obſerve the Altitude of the Sun *or of a* Star.

FOR to obſerve the Altitude of the *Sun* or any *Star*, we uſe a moveable Quadrant EAD, with fixed ſights A, B, or a Teleſcope placed along one of its ſides, and a Plumb line AC hanging from its Center. The Quadrant being placed in a Vertical Plane muſt be turned upwards and downwards, till the Rays of the *Sun*, paſſing thro' the hole of the firſt Sight next the Center, fall upon the hole of the other; or till the *Sun*'s Image appears in the *Focus* of the Teleſcope, and then the Quadrant being kept in this Poſition, the Plumb Line or Thread will ſhew the Arch EC which meaſures the Altitude of the *Sun*. For produce AC to the *Zenith* Z, and let AH be an *Horizontal* Line. The Angles EAB and ZAH are equal being both Right; but the Angles BAC and ZAS are likewiſe equal, they being vertical to each other: wherefore taking away equal Angles, there will remain the Angle EAC equal to the Angle SAH. But the Arch EC meaſures the Angle EAC, and the Arch of the Vertical between the *Sun* and the *Horizon* meaſures the Angle SAH; and therefore this Arch or the *Sun*'s Altitude and the Arch EC are ſimilar or like Arches. But if the height of a *Star* be to be obſerved, inſtead of the Irradiation of Beams as in the *Sun*, we muſt look thro' both Sights, or the Teleſcope for the *Star*; and when we can ſo ſee it, then the Thread will ſhew the Altitude of the *Star*. The Meridian Altitude of the *Sun* or *Star* is known by obſerving when the Altitude is greateſt, for then the *Sun* or *Star* attains his greateſt height, being then in the Meridian.

Plate XVII. Fig. 1.

How to obſerve the Latitude of a Place.

THE knowledge of the Latitude of the place is the Foundation of all *Aſtronomical* Obſervations, without which we can know nothing, and therefore it is firſt accurately to be obtained, and becauſe

cauſe we have ſhewed the Altitude of the *Pole* to be always equal to the Latitude, we can beſt find our Latitude by obſerving the *Pole's* height. But becauſe the *Pole* is only a Mathematical Point, and no ways to be perceived by our Senſes, we cannot find its height by the ſame Method as we did that of the *Sun* or *Stars*. And therefore we muſt take another way for finding it.

The Invention of the Meridian Line.

And firſt we muſt find the Section of the Plane of the Meridian with the *Horizon*, which Section is called the Meridian Line. This is obtained by erecting a *Gnomon* or Perpendicular upon the *Horizon* for to caſt a Shadow, and at the Foot of the *Gnomon*, at that Point which is directly under the top Point which caſts the ſhadow, there muſt be deſcribed a Circle, on whoſe Circumference the Shadow of the top Point may fall before Midday, and that Point of the Circumference where the Shadow comes muſt be carefully marked. Again after Midday obſerve the Point where the Shadow comes again to the ſame Circumference; and let the Arch between the two Points of Shadow be biſected, or cut into equal Parts. A Line drawn from the Center to the Point of Biſection will be the Meridian Line: For the *Sun* before and after Midday being equally high, is equally diſtant from the Meridian, or is in two Vertical Circles which make on each ſide equal Angles with it. Place therefore the Quadrant on the Meridian Line, ſo that its Plane may be in the Plane of the Meridian, and then take ſome *Star* near the *Pole* which never ſetts, and obſerve both its greateſt and leaſt Altitude.

Plate XVII. Fig. 2.

Let the greateſt be S O and the leaſt *s* O; the difference of their Altitudes is the Arch *s* S, the half of which P S or P *s*, deducted from the greateſt Altitude S O, or added to the leaſt *s* O, will give P O the Altitude of the *Pole* above the *Horizon*, which is equal to the Latitude of the Place. If the Theory of the *Sun* be known, from his Declination we may find out the Latitude of the place in this manner: Obſerve the Meridian diſtance of the *Sun* from the Vertex or *Zenith*, which is always the Complement of his Altitude; and add to this the Sun's Declination, when the Place and he are on the ſame ſide of the Equator; or ſubſtract the Declination when they are on different ſides, the Sum or Difference is always equal to the Latitude: But when the Declination of the Sun is greater than the Latitude of the Place, which is known from the Sun's being nearer to the Elevated Pole than the Vertex of the Place is, as it will often happen in the Torrid Zone; then the Difference between the Sun's Declination and the Sun's Zenith Diſtance is the Places Latitude.

How to obſerve the Obliquity of the Ecliptick.

HAVING once found out the Latitude of the Place, the Obliquity of the Ecliptick, or its Inclination to the Equator is eaſily obtained, by obſerving about the Summer Solſtice the Sun's leaſt Diſtance from the Vertex: If this Diſtance be ſubſtracted from the Latitude of the Place, when the Place is nearer to the Pole than the Sun is, the remainder will ſhew the greateſt Declination of the Sun, which is equal to the Obliquity of the Ecliptick. Moſt Aſtronomers make the greateſt Declination of the Sun, or the Obliquity of the Ecliptick to be 23 ½ Degrees; but the more accurate Obſervations of our Modern Aſtronomers ſhew it to be one Minute leſs.

How to find the Declition of the Sun or Star.

BY the ſame Method, the Declination of the Sun for any Day, or that of a Star may be taken; for when the Sun or Star is nearer to the Equator than the Place, take the Difference between the Latitude of the Place and the Meridional Diſtance of the Sun or Star from the Vertex, and we ſhall have the Declination: But if the Vertex of the Place lye between the Sun or Star and the Equator, then the Sum of theſe two Quantities is the Declination.

To find the Sun's Right Aſcenſion.

Plate XVII. Fig. 3.

HAVING the Declination of the Sun, it is eaſy to find his Right Aſcenſion and Place in the Ecliptick, by the Solution of a Right Angled Spherical Triangle. For let ÆQ be the Equator, ÆC the Ecliptick, S the Sun: from which let fall on the Equator a Circle of Declination SD, and then the Arch S D will be the Sun's Declination. And therefore in the Right-Angled Triangle Æ S D we have S D and the Angle Æ: We can therefore from thence find by ſpherical *Trigonometry* the Arch Æ D, which is the right Aſcenſion of the Sun, and Æ S, which gives his Place in the Ecliptick; and likewiſe the Angle Æ S D, the Inclination of the Circle of Declination or of the Meridian with the Ecliptick. So likewiſe in the Right-Angled Triangle Æ S D, if we have the ſide Æ D, which is the Right Aſcenſion, the Angle Æ being conſtant and known, we may eaſily find the ſide S D, which is the Declination of the Point of the Ecliptick S, which comes to the Meridian together with D, and is then call'd the *Medium Cœli*, or Mid-heaven; as alſo the Angle Æ S D the Inclination of the Meridian to the Ecliptick. Or laſtly, if Æ S the Longitude of the Point S be known, we can from it find its Right Aſcenſion and Declination, together with the Angle D S C, of the Ecliptick and Meridian.

The Apparent Motion of the Sun in the Ecliptick is not equable.

IF the Declination of the Sun by the Method we have ſhewed be daily obſerved, we can from thence collect the Apparent Motion of the Sun in the Ecliptick, which is always equal to the Motion the Earth really has in the ſame time. Now by Obſervation we find that the Sun does not move equably, or always with the ſame Velocity in the Ecliptick: And therefore the real Motion of the Earth muſt be unequal, and not conſtantly the ſame; in the Summer Solſtices the Earth has a ſlower Motion, in the Winter time it moves quicker: And this happens, becauſe the Earth by its real Motion is carried in the Perimeter of an Ellipſe, which has the Sun in one of its *Foci*; round which it revolves in ſuch a manner, that a Line drawn from the Sun to the Earth, and by an Angular Motion carrying the Earth along with it, doth always ſweep or deſcribe Elliptick *Area's* or Spaces proportional to the times in which they are deſcribed.

To find the Right Aſcenſion of the Stars.

HAVING the Place of the Sun in the Eclip- tick, by the help of it, and a good Pendulum Clock, we may find the Right Aſcenſions of all the *Stars*: For which purpoſe the Motion of the Clock muſt be ſo adjuſted, that the Hand may run thro' the twenty-four Hours in the time that a Star leaving the Meridian will arrives at it again; which Time is ſomewhat ſhorter than the Natural Day, becauſe of the Space the *Sun* moves thro' in the mean time Eaſtward. The Clock being thus adjuſted, when the Sun is in the Meridian fix the Hand to the Point, from whence we are to begin to reckon our Time; And then obſerve when the Star comes to the Meridian, and mark the Hour and Minute that the Hand then ſhews: The Hours and Minutes deſcrib'd by the Index turn'd into Degrees and Minutes of the Equator, will give the Difference between the Right Aſcenſion of the Sun and Star; which Difference being added to the Right Aſcenſion of the Sun, will give the Right Aſcenſion of the Star. Now if we know the Right Aſcenſion of any one Star, we may from it find the Right Aſcenſions of all the others which we ſee, by marking the Time upon the Clock between the arrival of the Star whoſe Right Aſcenſion we know to the Meridian, and another Star whoſe Aſcenſion is to be found. This Time converted into Hours and Minutes of the Equator, will give the Difference of Right Aſcenſions; from whence, by *Addition*, we collect the Right Aſcenſion of the Star which was to be found out.

The Right Aſcenſion of one Star being known; how from thence to find the Right Aſcenſions of the reſt.

BUT by knowing the Right Aſcenſion of one Star, the Right Aſcenſions of the reſt are eaſieſt found by the following Method; where there is no need of waiting till the Stars come to the Meridian. We only uſe a Teleſcope, in whoſe *Focus* there are fixed four Threads extended, two of which as A B, C D cut one another at Right-Angles, and other two E F, G H make half Right-Angles with the former two, at their common Interſection O: Then the Teleſcope is to be directed to a Star, whoſe Right Aſcenſion and Declination are known.

Lecture XIX.

Plate XVII. Fig. 4.

AND then the Teleſcope is to be conſtantly turned till the Star be ſeen in the Line A B, ſo as its apparent diurnal Motion may be along that Line; in which Poſition the Right Line A B will repreſent a Portion of that Parallel Circle the Star deſcribes, it being in a parallel to its Plane: And becauſe the Line C D cuts it at Right-Angles, it will repreſent ſome Horary Circle. Fix then the Teleſcope very firm in this Situation, and mark the Time according to the Clock, when the Star, whoſe Aſcenſion is known, comes to the Line C D. Then again obſerve any other Star with the Teleſcope, which will appear to move in ſome Line L K that is parallel to A B, and mark likewiſe the time when it comes to the Horary Circle C D in Q. The Difference of Times between the arrival of the firſt Star to the horary Circle, and the coming of this laſt to the ſame, converted into Degrees and Minutes of the Equator, will give the Difference of their Right Aſcenſions: And therefore if the Right Aſcenſion of one of them be found, we may from thence collect the Right Aſcenſion of the other.

BECAUSE the Angles Q H O and Q O H are equal, being each half a right, Q H will be equal to Q O. Now if we mark the Time between the coming to the Thread O H, and its touching the Thread O Q, we ſhall have the time the Star takes to deſcribe the Portion H Q of the Parallel. This Time being turned into Degrees and Minutes, will give the Number of Degrees and Minutes of the Portion Q H. But the Arch of the Horary great Circle is equal to this Arch Q H. Now in unequal Circles the Degrees and Minutes that equal Arches contain are reciprocally as the Radii or Semidiameters of the Circles, as we ſhall ſhew hereafter. As the Radius therefore of the great Circle is to the Radius of the Parallel L K (which does not ſenſibly differ from the Radius of the known Parallel A B.) that is, as the Radius is to the Sine of the Stars diſtance from the Pole, ſo the Number of Degrees and Minutes in the Arch H Q of the Parallel, to the Number of Degrees and Minutes in the Arch O Q of the great Circle; which therefore will be known by the Rule of Proportion. But Q O is the Difference of the Declinations of the Star which deſcribes the Parallel A B and of that which deſcribes the Parallel L K; therefore from the Declination of one of theſe Stars being known, we can find the Declination of the other. And by this Method the Right Aſcenſions and Declinations of moſt Stars may be obſerved.

THAT in unequal Circles the Numbers of ſimilar Parts, as Degrees and Minutes, that are in Arches equal in bigneſs, are reciprocal to the Radii of the Circles, may be thus demonſtrated. Imagine two unequal Circles whoſe Center is C, and in them equal Arches B E, A F: Draw from the Center C B, C E, cutting from the leſſer Circle the Arch A D. The Arches A D and B E will contain equal Numbers of Degrees and Minutes. And becauſe A F and B E are equal, A D will be to A F as A D is to B E. But A D is to B E as C A is to C B; therefore A D will be to A F as CA is to C B. But A D is to A F as the Number of Degrees and Minutes in A D or in B E is to the Number of Degrees and Minutes in A F. Wherefore the Number of Degrees and Minutes in B E is to the Number of Degrees and Minutes in A F, as C A is to C B; or in a reciprocal Proportion of the Radii of the Circles. Which was to be demonſtrated.

Plate XVII. Fig. 5.

Having the Right Aſcenſion of a Star and its Declination to find its Longitude and Latitude.

HAVING the Right Aſcenſion and Declination of a Star, its Longitude and Latitude may be found out by the Solution of a ſpherical Triangle. For imagine B P Q to paſs thro' the Poles of the Equator and Ecliptick; this Circle is the *Solſtitial Colure.* Let Æ Q be the Equinoctial, E C the Ecliptick, whoſe Section with the Equinoctial is ♈, and let S be a Star, thro' which paſſes the Circle of Declination P S F, cutting the Equinoctial at F: The Arch ♈ F is the Right Aſcenſion of the Star, and S F its Declination.

Plate XVI. Fig. 6.

Draw thro' the Pole of the Ecliptick B and the Star the Circle of Latitude B S O, meeting with the Ecliptick in O: Then ♈ O will be the Longitude of the Star, and S O its Latitude. In the ſpherical Triangle B S P, we have the ſide P S which is the Complement of the Declination, and the ſide B P, which is equal to the Arch that meaſures the Inclination of the Equator and the Ecliptick: Beſides which, we have the Angle which is meaſured by the Arch F Q the Complement of the Right Aſcenſion; and therefore we have the Angle B P S its Complement to two right Angles. And therefore in the Triangle B P S having three of its conſtituent Parts, we may find firſt the Angle P B S, whoſe meaſure is the Arch O C, and its Complement to a Quadrant is the Arch ♈ O, which is the Longitude of the Star. We can likewiſe from the ſame Things given find the Arch B S, whoſe Complement to a Quadrant is S O, the Latitude of the Star. After the ſame Method, if the Longitude and Latitude of a Star be known, we may from thence find its Right Aſcenſion and Declination.

By comparing the Places of the fixed Stars, as they were deliver'd to us by the Antients, with what they now obtain, we find that their Latitudes are much the ſame they were formerly; but their Longitudes or Diſtances from the firſt of ♈ have been found to encreaſe continually: Not that the Stars have a real progreſſive Motion; but becauſe the Equinoctial Points have a Motion backwards, and the Longitudes are computed from them. The Longitude of any fixed Star obſerved by the Antient Aſtronomers, compared with the Longitude it has at preſent, ſhews the Quantity of this Regreſſion of the Equinoctial Points to be about one Degree in 72 Years.

BY the Method we have ſhewed, the Longitudes and Latitudes of the Fixed Stars are found, and they and their Places are ranked in a Catalogue, which being once eſtabliſhed, the Places of the Planets and Comets are eaſily known by Obſervation and Computation. For if the Diſtances of any Planet or Comet from two Fixed Stars of known Longitude and Latitude be taken by Obſervation, we may by that means determine the Longitude and Latitude of the Planet or Comet in the following manner.

Plate XVII. Fig. 7.

Let E F be a Portion of the Ecliptick, whoſe Pole is B, and let A and C be two Stars, whoſe Longitudes and Latitudes are known, and P a Planet, whoſe Diſtances from the ſame Stars are known by Obſervation. In the Triangle A B C, having A B and C B the Complements of the Latitudes of the two Stars, and the Angle A B C, whoſe meaſure is the Arch E F, the Difference of Longitude of the two Stars; from thence we may find A C the Diſtance of the Stars, and the Angle B C A. Again, in the Triangle A P C we have all the Sides, from which we may find the Angle PCA; which being ſubſtracted from BCA, will leave the Angle B C P. Laſtly, in the Triangle B C P, we have the ſides B C, C P, and the Angle P C B; from which we can find the Angle P B C, whoſe meaſure is O F the Difference of Longitude of the Star C and the Planet. We can alſo find the Arch P B the Complement of the Latitude of the Planet.

AFTER the ſame Method, if we have the Diſtances of a Planet from two Fixed Stars, whoſe Right Aſcenſions and Declinations are known, we may find out the Right Aſcenſion and Declination of that Planet.

LECTURE XX.

Of the Twilight, *and of the Refraction of the Stars.*

The Air makes the Firmament lucid.

BESIDES other innumerable Conveniencies which we receive from the *Atmoſphere*, we have this great Advantage, that while the Sun ſhines, it makes the Face of the Heavens or Firmament to appear lucid and bright; for if no *Atmoſphere* ſurrounded and involved the Earth, only that part of the Heavens would appear to ſhine in which the Sun was placed: And a Spectator, if he ſhould turn his Back to the Sun, would immediately perceive it as dark as Night; and even in the Day-time while the Sun ſhined, the leaſt Stars would be ſeen ſhining, as they do now in the cleareſt Night; ſince in that Caſe there would be no ſubſtance to reflect the Rays of the Sun to our Eyes, and all the Rays which do not fall upon the Surface of the Earth, paſſing by us, would either illuminate the Planets and Stars, or ſpreading themſelves out into infinite Space, would never be reflected back to us.

BUT ſince there is an *Atmoſphere* covering the Earth, which is ſtrongly illuminated by the Sun, it reflects the Light back upon us, and makes the whole Heavens to ſhine; and that ſo ſtrongly, that by reaſon of its Splendor, it obſcures the faint Light of the Stars, and renders them inviſible.

Plate XVI front . p . 232

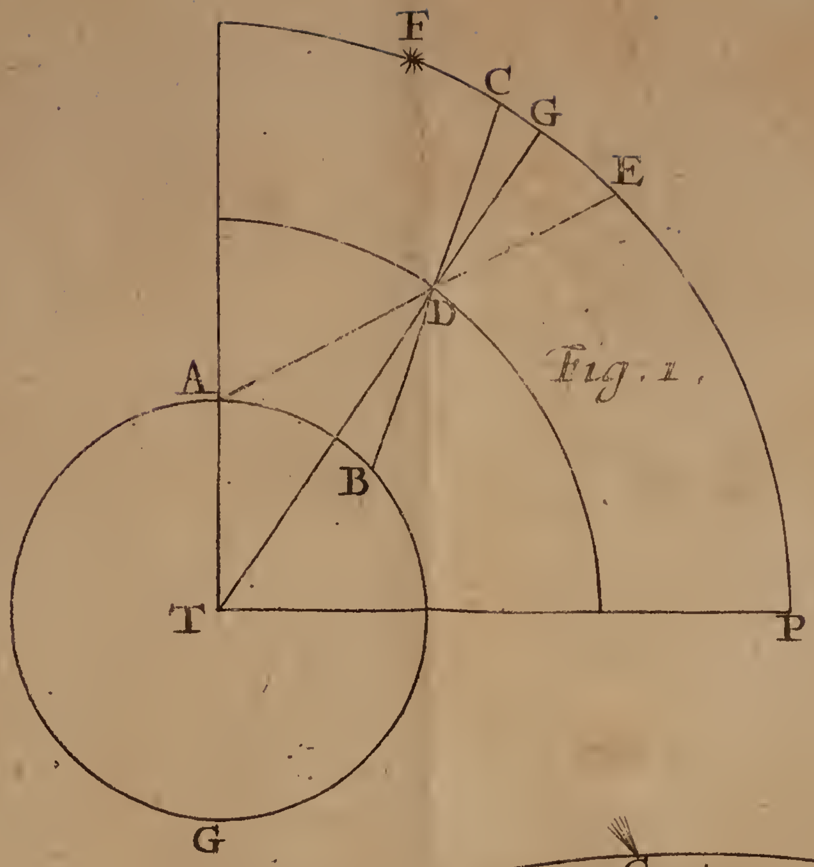


Fig. 1.

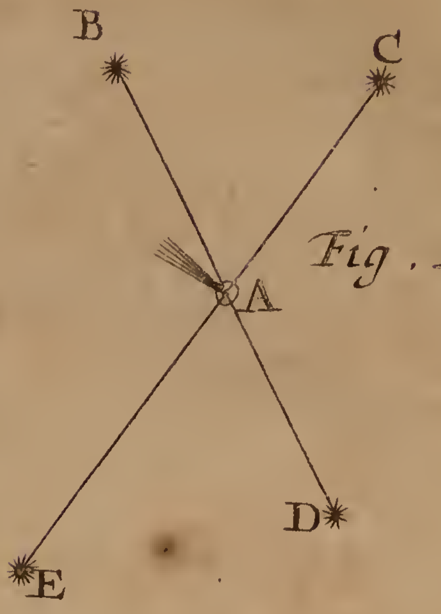
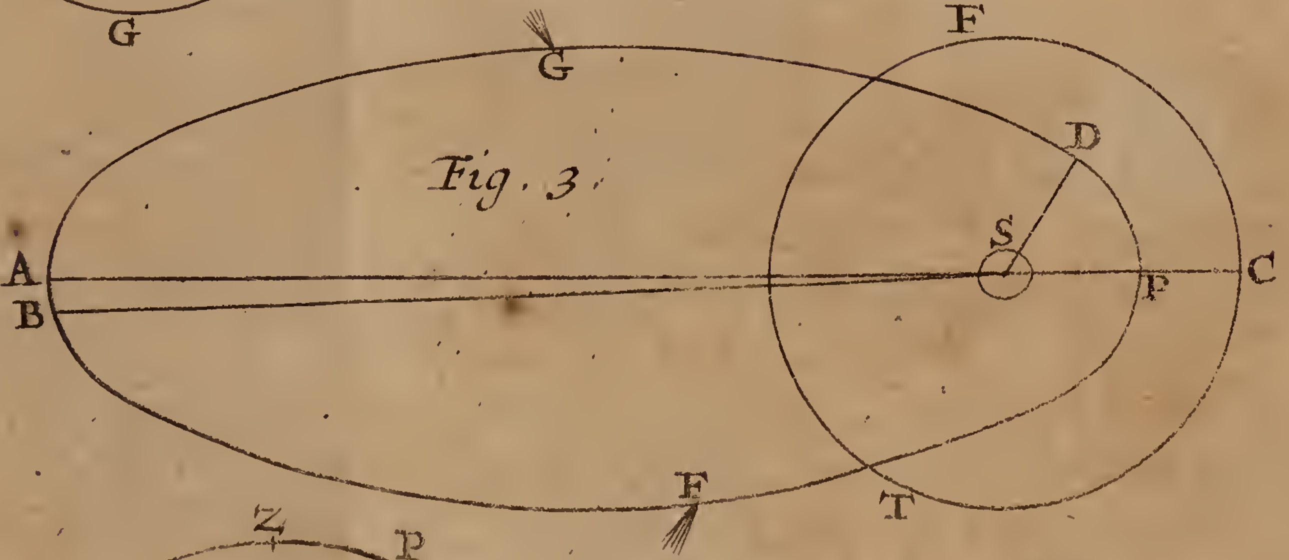


Fig. 2.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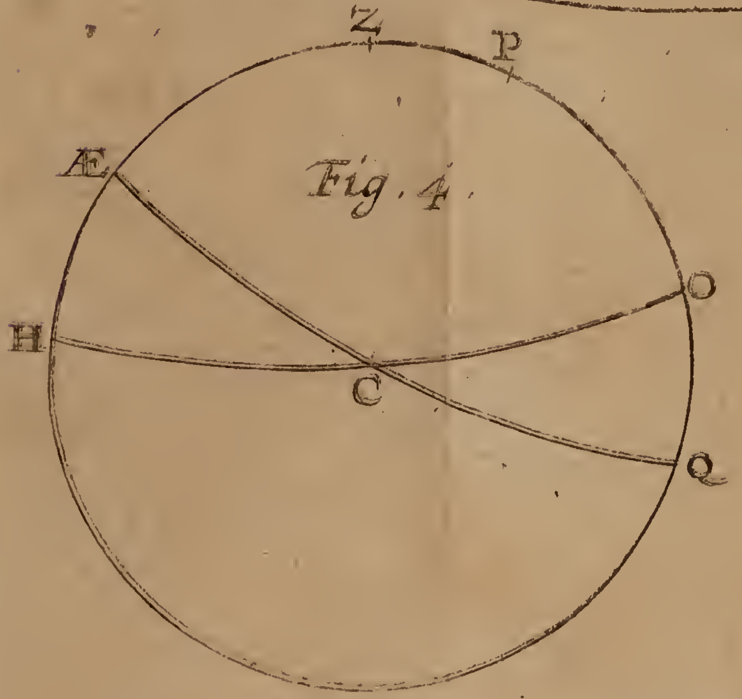
Fig. 4.

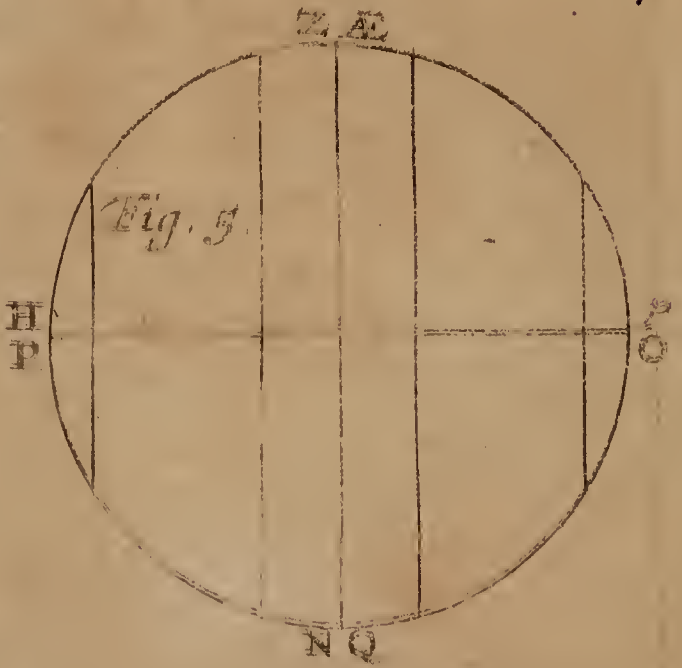
Fig. 5.

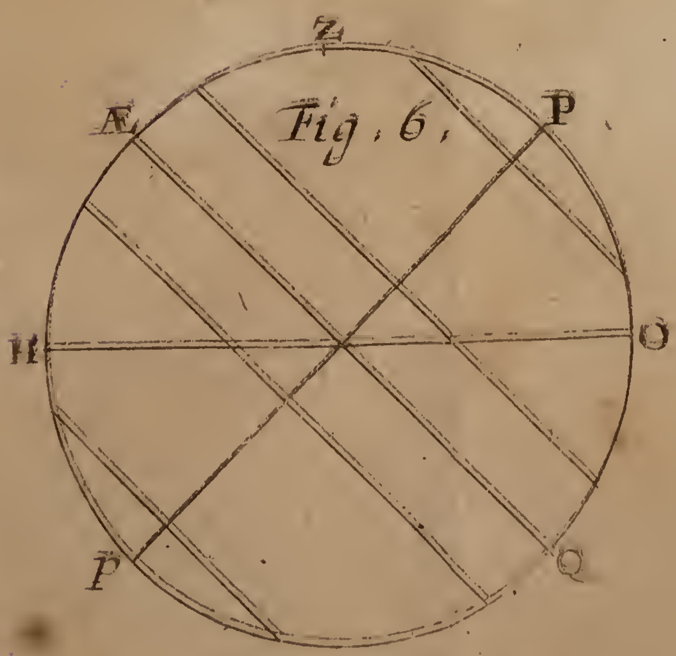
Fig. 6.

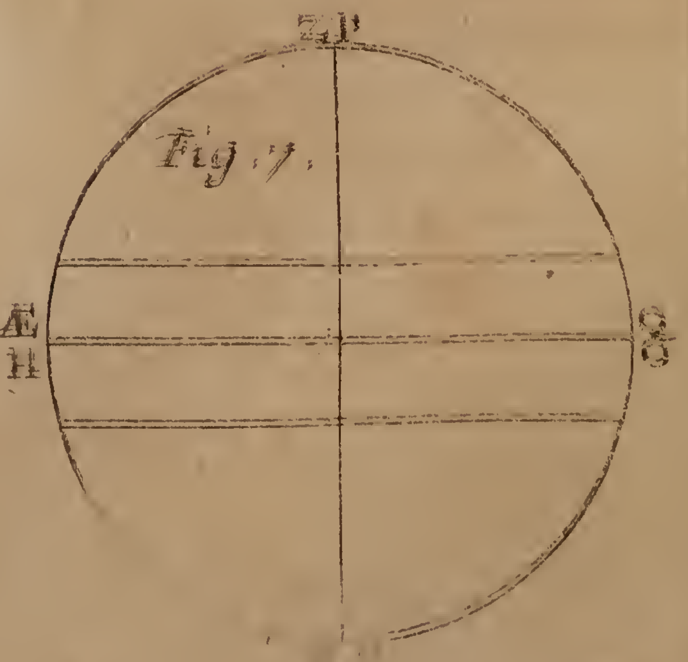
Fig. 7.

Plate XVII

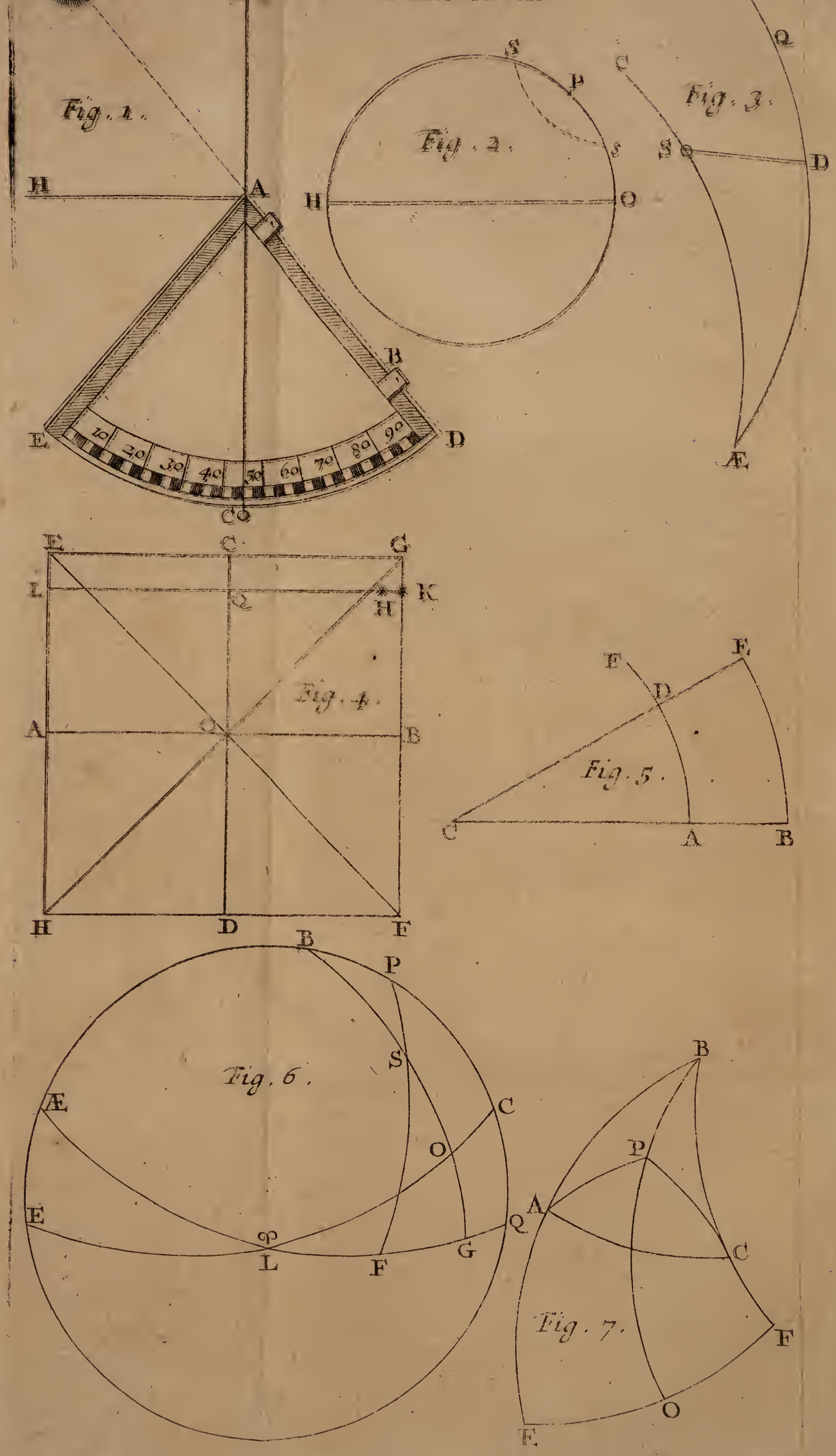
Fig. 1.
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Fig. 2.
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Fig. 3.
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Fig. 4.
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Fig. 5.
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Fig. 6.
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Fig. 7.
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The Cauſe of the Crepuſcles.

IF there were no *Atmoſphere*, the Sun immediately before his ſetting, would ſhine as briskly as at Noon; but in a Moment, as ſoon as he is ſet, we ſhould have the Face of the Earth in as great Darkneſs as it would be at Midnight: So quick a Change, and ſo ſuddain a paſſing from the greateſt Light to the greateſt Darkneſs, would be very inconvenient to the Inhabitants of the Earth. But by means of the *Atmoſphere* it happens, that tho' after Sun ſetting we receive no direct Light from the Sun, yet we enjoy its reflected Light for ſome Time; ſo that the Darkneſs of the Night comes not ſuddainly, but by Degrees. For after the Earth by its Revolution round its Axis has withdrawn us from the ſight of the Sun. The *Atmoſphere* which is higher than we are, will ſtill be illuminated by the Sun; ſo that for a while the whole Heavens will have ſome of his Light imparted to it. But as the Sun goes ſtill lower under the Horizon, the leſs is the Air illuſtrated by him: So that when he is got as far as 18 Degrees lower than the Horizon, he no longer enlightens our *Atmoſphere*, and then all that part thereof that is over us becomes dark.

SO likewiſe in the Morning, as ſoon as the Sun comes within 18 Degrees of the Horizon, he begins again to enlighten the *Atmoſphere*, and to diffuſe his Light thro' the Heavens: So that its Brightneſs does ſtill increaſe, till the Sun riſes and makes full Day. This ſmall Illumination of the *Atmoſphere*, and ſtate of the Heavens between Day and Night, is what we call the *Twilight*, which is obſerved in the Morning before the Sun's riſing, and at Night after his ſetting; in *Latin* it is named the *Crepuſculum.*

Plate XIX. Fig. 1.

TO make this plainer, imagine the Circle A D L on the Surface of the Earth, in the Plane of the vertical Circle in which the Sun is when under the Horizon. Let there likewiſe be another concentrical Circle C B M in the ſame Plane, including that Portion of the Air that reflects the Sun's Beams: And ſuppoſe the Eye to be on the Earth's

Lecture XX.

Earth's Surface at A, whoſe ſenſible Horizon is A N. Since no Line can be drawn to A between the Tangent A N and the Periphery A D, by the 16th of the *Third Element*; it is plain, that when the Sun is under the Horizon no direct Rays can come to the Eye at A: But the Sun being in the Line C G, a Line may be drawn from him to C, ſo that the Particle C may be illuminated by the direct Rays of the Sun; which Particle may reflect thoſe Rays to A, where they may enter the Eye of the Spectator: And by this means the Beams of the Sun's Light illuminating an innumerable multitude of Particles, may by them be reflected to the Spectator in A. Let the Tangent A B meet with the Surface of the Orb of Air that reflects the Light in B; and from B draw B D, touching the Circle A D L in D, and let the Sun be in the Line B D at S: Then the Ray S B will be reflected into B A, and will enter the Eye, becauſe of the Angle of Incidence D B E being equal to the Angle of Reflection A B E: And that will be the firſt Ray that reacheth the Eye in the Morning, and then the dawning begins; or the laſt which falls upon the Eye at Night, when the *Twilight* ends. For when the Sun goes lower down, the Particles at B can be no longer illuminated.

Another Cauſe of the Twilight.

THE Reflection of the *Atmoſphere* does not ſeem to be the only cauſe of the *Twilight*; but there is an Ætherial Air or *Atmoſphere* likewiſe round the Sun, which ſhines after the Body of the Sun is ſet: This Orb of the Sun's *Atmoſphere* riſing ſooner, and ſetting later than the Sun it ſelf, ſhines out at Mornings and Nights in a circular Figure, it being a Segment of the Sun's *Atmoſphere* cut by the Horizon; and its Light is quite of another ſort than that which is made by the Reflection of our *Atmoſphere*. But the Duration of the *Twilight* that ariſes from the Sun's *Atmoſphere*, is ſhorter much than that made by the Reflection of the Earth's *Atmoſphere*, which does not end till the Sun comes to be 18 Degrees below the Horizon,

zon, or thereabouts. But there can be no certain bounds fixed for the Beginnings and Endings of the *Twilights*; for their Lengths depend on the quantity of Matter in the Air which is able to reflect Light, and on the Height of the *Atmoſphere.* In the *Winter* the Air being condenſed by the cold is low, and on that Account the *Twilights* are ſooner over. In the *Summer* the Air is rarify'd by Heat, and therefore being higher remains longer illuminated by the Sun, ſo that the *Twilights* laſt the longer: Alſo the Duration of the *Twilight* is ſhorter in the Morning than at Night. We generally reckon that the *Twilight* begins or ends, when in the Morning the Stars of the ſixth Magnitude diſappear, or in the Evening when they firſt come to be ſeen; the light of the Air before that rendring them inviſible. *Ricciolus* obſerved at *Bononia* that the Morning *Twilight* about the Time of the *Equinoctles,* laſted an Hour and 47 Minutes; but in the Evening two Hours, and did not end till the Sun was 20 Degrees under the Horizon: But in *Summer* the Morning *Twilight* was three Hours and 40 Minutes long; the Evening *Twilight* ſcarcely ending till Midnight.

The Height of the Atmoſphere *meaſur'd by an Obſervation of the* Twilight.

HENCE if we have the Time of Beginning of the *Twilight* in the Morning, or the end of it at Night, we may find the Height of the Air that reflects the Light; for then the *Twilight* ends, when a Ray of Light from the Sun touches the Globe of the Earth, and is by the higheſt Air reflected to our Eyes: For having the Time, we can find the Depreſſion of the Sun below the Horizon, and from thence the Height of the Air. For let S B be a Ray of Light touching the Earth, which is reflected, by a particle of Air in its higheſt Region, in the horizontal Line A B; the Angle S B N is the meaſure of the Depreſſion of the Sun below the Horizon: And becauſe A B is alſo a Tangent, the Angle A E D at the Center is equal to the Angle S B N; and its half, that is the Angle A E B, is equal to half S B N or half the Depreſſion of the Sun. Suppoſe the Depreſſion of the Sun at the beginning or end of *Twilight* be 18 Degrees; then the Angle A E B will be 9 Degrees, which would be true, did the Ray S B paſs thro' the *Atmoſphere* without Refraction: But becauſe it is refracted and bent towards H, we muſt diminiſh the Angle A E B by a quantity equal to the Horizontal Refraction, which is about half a Degree: And therefore the true meaſure of the Angle A E B is 8½ Degrees. Moreover, A E is to B H as the Radius is to the exceſs of the Secant of the Angle A E B above the Radius, that is as 100000 is to 1110. Therefore if the Semidiameter of the Earth be in round Numbers 4000 Miles, B H the height of the *Atmoſphere* which reflects the Sun's Rays will be about 44 Miles; for as 100000 is to 1110, ſo is 4000 to 44.

Under the Equator the time of the Twilight *is ſhort.*

IN a right Poſition of the Sphere the *Twilights* are quickly over; becauſe the Sun deſcends conſtantly nearly in a perpendicular; but in an oblique Sphere they laſt longer, the Sun deſcending obliquely; and the more oblique the Sphere is, that is the greater the Latitude of the Place is, ſo much longer laſt the *Twilights*: So that all they who are in above 48 Degrees Latitude, in the *Summer* near the Solſtices, have their *Atmoſphere* illuminated the whole Night, and the *Twilight* laſts till the Sun-riſing, without any compleat darkneſs.

Under the Poles they laſt ſome Months.

IN a parallel Sphere the *Twilight* laſts for ſeveral Months; ſo that the Inhabitants have either the direct or reflex Light of the Sun for almoſt all the Year.

The Circle terminating Twilight.

IF below the Horizon you conceive a Circle to be drawn parallel to the Horizon, and at a diſtance from it equal to the Depreſſion of the Sun at the end of the *Twilight*: This leſſer Circle is called the *Circle which terminates the* Twilights; for whenever the Sun by its apparent diurnal Motion reaches this Parallel, the Morning *Twilight* begins, or the Evening ends, in whatever parallel of the Equator the Sun is.

The Arches of the Crepuſcles or Twilight.

IN the Figure let HQO be the Horizon, V*a* X the Circle parallel to it terminating the *Twilight*, the Circle HZO the Meridian, ÆQ*a* the Equator. It is manifeſt that the more oblique the Equator is to the Horizon, ſo much the greater are the Arches of the Equator and its Parallels, intercepted between the Horizon and the terminating Circle V*a* X. The Arches QR, *d a*, C *e*, G *h*, K *l*, are called the Arches of the *Twilights*, becauſe they determine their Duration: And as each Arch has a bigger or leſs proportion to its Circle, ſo will the *Twilight* when the Sun is in that Parallel, be longer or ſhorter. In the Circle bounding the *Crepuſcles* take any Point *a*, thro' which paſſes a Parallel to the Equator *d a*; and thro' *a* imagine a great Circle to be drawn as M *a* N, touching the Circle of perpetual Apparition: And ſince the Horizon likewiſe touches the ſame Circle, theſe two Circles will make equal Angles with the Equator and its Parallels; for the meaſure of each Angle is the diſtance of the Parallel from its great Circle. So likewiſe all the Arches of the Equator, and its Parallels between the Horizon and the Circle M *a* N are ſimilar, by *Prop.* 13, Book II. *Theodoſius*'s Sphericks. This Circle M *a* N will either cut the bounding Circle V*a* X in two Points, or touch it in one. Let it firſt cut it in two Points *a* and *h*; and therefore the Arches of the Parallels *d a*, G *h* are ſimilar: Wherefore when the Sun by its diurnal Motion deſcribes theſe two Parallels, the *Twilights* are equal; But while he deſcribes any intermediate Parallel as C *e*, the Time of the *Twilight* is ſhorter; for in this caſe C *m* the Arch of *Twilight* is leſs than C *e*, which is ſimilar to the Arch *d a* or G *h*, and C *e* and *d a* are deſcribed by the Sun in equal times. But when the Sun is in Parallels that are at a greater diſtance from the Equator than G *h*, the *Twilights* laſt longer; for the *Twilight* Arch *l* K is greater than *q* K, which is deſcribed by the Sun in the ſame time as the Arch of the *Crepuſcle* G *h*.

Plate XIX. Fig. 2.

The different Durations of the Twilights.

WHILE the Sun is in Parallels that are towards the elevated Pole, the *Twilights* do conſtantly grow longer, according as thoſe Parallels approach the Poles: For the *Twilight* Arch *o p* is longer in being deſcribed than Q R, and Y U the ſame way is longer than *o p*. But if the Sun deſcribe the Parallel S *t*, it never will meet with the bounding Circle, and then the *Twilight* laſts the whole Night long.

HENCE ariſes a great Difference between the increaſe of the *Twilight* and its decreaſe and the encreaſe and decreaſe of Days and Nights. For while the Sun moves from the beginning of ♋ to the firſt of *Capricorn*, all that time the Days conſtantly decreaſe, and the Nights increaſe: But in the *Twilight* it is otherwiſe; for tho' the *Twilight* and Days are at the longeſt when the Sun is in the firſt degree of ♋, and then they both decreaſe together; yet the times of *Twilight* do not continually decreaſe till the Sun comes to ♑, but there is a certain Point between ♎ and ♑, to which when the Sun arrives, we have the ſhorteſt *Twilight*. From thence the *Twilights* will begin to encreaſe again, and there will be one Arch of *Twilight* ſimilar to that when the Sun is in the Equator, before he reaches ♑: And if the Sun ſhould go further South even beyond the Tropick, the *Twilights* would ſtill increaſe, altho' the Days decreaſed. And altho' the Days from the beginning of the Sun's entry into ♑ do conſtantly encreaſe, yet the *Twilights* grow ſhorter till the Sun comes to a point between ♑ and ♈, in which again we have the ſhorteſt *Twilight*: This appears plain by what we are here to demonſtrate in the next place.

Plate XIX. Fig. 3.

2*dly*, LET the Circle M *a* N touch the bounding Circle in one point, which ſuppoſe to be *a*, thro' which draw the Parallel to the Equator *d a*; I ſay that when the Sun is in this Parallel the *Twilight* will be the ſhorteſt of all. For becauſe the Arches of the Parallels intercepted between the Horizon and the Circle M *a* N are all ſimilar, they will be deſcribed by the Sun in equal times: But becauſe the *Twilight* Arches *c e* and *g h* are greater than *c m* or *g i*, the Sun will be longer in moving thro' the Arch *c e* than *c m*, and thro' the Arch *g h* than *g i*; that is longer than in deſcribing the Arch *d a*, which Arch therefore is the ſhorteſt *Twilight*.

The time of the ſhorteſt Twilight *inveſtigated.*

THE Diſtance of that Parallel from the Equator in which is the ſhorteſt *Twilight*, is thus inveſtigated. Becauſe the Circle M *a* N and the Horizon H O touch the ſame Parallel, which is the Circle of perpetual Apparition, they will both be equally inclined to the Equator: And therefore the Angle *a n* T of the Equator and the Circle M *a* N, is equal to the Angle F Q *d* of the Equator and the Horizon. Thro' the Zenith Z and the Point *a* draw the vertical Circle ZY*a*, cutting the Equator in the point T. The ſpherical Triangles *a n* T, T Q Y, are mutually equiangular to each other, becauſe the Angles at *a* and Y are right; and we have ſhewed that the Angles at Q and *n* are equal; alſo the Angles at T are equal, being vertical to each other: Theſe Triangles then being equiangular are alſo equilateral; and therefore T *a* will be equal to TY, or to half the diſtance of the bounding Circle from the Horizon: Moreover, *a n* is equal to Q *d*, by 13. *Prop.* Book II. *Theod.* for F R and *d a* are parallel, and therefore *d* Q is equal to Q Y.

IN the ſpherical Triangle T Q Y rectangular at Y, we have the ſide T Y half the diſtance of the bounding Circle from the Horizon; as alſo the Angle Y Q T equal to F Q *d*, which meaſures the Complement of the Latitude of the place; wherefore we can find Q Y, and Q *d* which is equal to it. From the Point *d* to the Equator draw the Circle of Declination *d* F; and in the ſpherical Triangle *d* Q F, we have *d* Q and the Angle Q, by which we can find the Arch *d* F, the Declination of the Parallel of the leaſt *Twilight* from the Equator, which was to be found.

The ſame Problem *ſolved by a ſingle Analogy.*

THIS *Problem* might have been ſolved by one ſingle Analogy. For in the Triangle TQY, the Radius : Tang. TY : : Co-tang. Q : Sin. QY or to the Sin. of dQ: But the Sin. of Q : Coſin. of Q : : Rad. Co-tang. Q. Therefore by the Rules of the 5*th* Element, The Rad. multiplyed by the Sin. of Q, will be to the Tang. of TY into the Coſin. of Q, as the Radius is to the Sin. of Qd: But in the Right-angled Triangle QdF, Radius is to the Sine of Qd as the Sine of the Angle Q to the Sine of dF; wherefore Rad. × Sine Q will will be to Tang. of TY × Co-ſine of Q, as the Sine of Q to Sine of dF; and thence, *ex æquo*, it will be as Radius to Tang. of TY, ſo Co-ſine of Q or the Sine of the Latitude, to the Sine of the diſtance of the Parallel from the Equator. Having the Declination of the Sun, the time of the beginning of the Morning *Twilight*, which we call Break of Day, or the End of the Evening *Twilight* is thus to be found. Let op be the parallel of the Sun meeting with the bounding Circle in p; and draw thro' the Pole the Circle of Declination Pp. In the ſpherical Triangle PZp we have all the ſides; for ZP is the Complement of the Latitude, Pp the Complement of the Sun's Declination, and Zp equal to the Sum of a Quadrant and the diſtance of the bounding Circle from the Horizon $= Zl + lp$. From which we can find the Angle ZPp, and its Complement to two Rights pPV: and the Arch of the Equator meaſuring this Angle being converted into Time, will ſhew the beginning or end of *Twilight*.

The Duration of Twilight *determined.*

Refraction by the Atmoſphere.

THE *TERRESTIAL ATMOSPHERE* by reflecting the Sun's Beams not only produces the Morning and Evening *Twilight*, but it alſo bends and refracts the Rays of the Sun and all the Stars which fall on it, and changes their Directions by propagating the Light in other Lines, making the apparent Places of the Stars different from their true Places.

BY manifold Experiments we find that the Rays of a luminous Body, even of any viſible Object,

ject, when they fall upon a *Medium* or Diaphanous Body as Air or Water, of a different Denſity from that from whence they firſt proceeded; do not afterwards go directly in the ſame ſtrait Lines, but are broken or bended, and propagated as if they had proceeded from another point than they really did. And if the *Medium* on which the Rays fall be denſer than the firſt, they are bent towards a Line perpendicular to that Surface whereon they fall, at the point of Incidence; but if it be a *Rarer Medium*, in their bending they recede from the Perpendicular.

WE obſerve in Nature many effects of Refraction. A Staff, whoſe one part is immerged in Water and the other in the Air, appears broken; and that part which is in Water appears higher than it really is. All the Stars by Refraction appear higher or nearer to our Vertex than they would be, were there no Air, ſo that the Light might arrive to us without Refraction.

Plate XIX. Fig. 4.

LET ZV be a Quadrant of a vertical Circle in the Heavens deſcribed from the Center of the Earth T, under which is A B a Quadrant of a Circle on the Surface of the Earth, and G H a Quadrant on the ſurface of the *Atmoſphere*: And let S be any Star from which proceeds the Beam of Light S E, falling on the Surface of the Air in E. Now ſince this Ray comes from the Etherial Air much rarer than ours, or rather from a perfect Void, and falls on our *Atmoſphere*, which is denſe in compariſon of it; In E it will be refracted towards the Perpendicular: And becauſe the upper Air is rarer than that which is nearer the Earth, and grows ſtill denſer the nearer it is to us, this Ray of Light as it proceeds will conſtantly be refracted and bended, ſo that it will arrive at our Eye in the curve Line E A: Suppoſe the right Line A F to touch this Circle in A; according to the Direction A F the Ray of Light will enter the Eye at A. And becauſe all Objects are ſeen in the Line according to whoſe Direction the Rays enter the Eye and ſtrike upon the *Senſorium*; the Objects will appear in the Line A F, that is in the Heavens at Q, which is nearer to our Vertex than the Star really is. And it may even happen, that a Star which is below the Horizon may be ſeen above it. This Refraction is alſo the cauſe why the two great Luminaries the Sun and Moon, when one of them is above the Horizon and the other below it, both may appear above the Horizon; ſo that the Moon has been obſerved eclipſed, when ſhe was below the Horizon and the Sun above it.

By Refraction an Eclipſe of the Moon may be ſeen when ſhe is under the Horizon.

A Star in the Vertex or Zenith has no Refraction, for a perpendicular Ray goes ſtreight on; But the more obliquely the Ray falls upon the ſurface of the Air, ſo much the greater is the Refraction; ſo that the Horizontal Refraction is the greateſt of all. And a Star that is above 50 Degrees high has ſcarcely a ſenſible Refraction. In equal Altitudes the Refractions are equal: And therefore the Sun, Moon and fix'd Stars, at the ſame apparent height, have all the ſame Degree of Refraction; tho' the noble *Tycho Brahe*, the Reſtorer of *Aſtronomy* and the firſt obſerver of Refractions, thought otherwiſe: Hence if the Refractions of the Fixed Stars are known, we ſhall know likewiſe the Refractions of the Sun, Moon and Planets: And it is eaſier to find by Obſervation the Refraction of a Fixed Star than that of the Sun and Moon: For the Parallaxes of theſe Bodies not being exactly known, the Obſervations about their Refractions will be doubtful; but the Fixed Stars having no Parallax, all the difference between their true and obſerved Places is wholly owing to Refraction.

Where the Refraction greateſt; where the leaſt.

All the Stars at equal heights have equal Refractions.

THOSE Fixed Stars that riſe higher above the Horizon than 50 Degrees have their Declinations, Right-Aſcenſions, Longitudes and Latitudes accurately enough known; for in ſo great an Altitude the Refraction is next to nothing. Now theſe being known, we find the Refraction's near the Horizon by the following Method. Let O P Z H be the Meridian, H O the Horizon, Æ Q the Equa-

The Method of obſerving the Refraction.

Plate XIX. Fig. 5.

Equator, P the Pole, and the Vertex Z. Let A be a *Star* whoſe Refraction is to be found, and let Z D be a vertical Circle paſſing thro' the *Star*, whoſe apparent Place ſuppoſe to be C; the Arch A C is the Refraction. Let the apparent diſtance of the *Star* from the Vertex be obſerved, that is the Arch Z C: And at the time of the Obſervation take the Altitude of another *Star* which is ſo high that it is not liable to Refraction, with which find out the moment of Time the Obſervation was made; which may alſo be known by a good Pendulum Clock: By this Time and the Right-Aſcenſion of the Sun, we ſhall find the Point of the Equator which then culminates or is in the Meridian, that is the Point Æ. But we have alſo the Right-Aſcenſion of the *Star*, that is the Point B, where the Circle of Declination paſſing thro' the *Star* meets the Equator; and conſequently the Arch Æ B will be known, which is the meaſure of the Angle Z P A. Therefore in the ſpherical Triangle Z P A, having Z P the diſtance of the Pole from the Vertex, and P A the Complement of the *Star's* Declination, as alſo the Angle Z P A, we find out by *Trigonometry* the ſide Z A the true diſtance of the *Star* from the Vertex; from which ſubſtract ZC the apparent diſtance known by Obſervation, and there will remain A C the Refraction of the *Star*, which was to be found.

Another Method for finding the Refraction.

THE Refraction may likewiſe be found by obſerving the Azimuth of a *Star*, or the Arch of the Horizon between the Meridian and the Vertical Circle paſſing thro' the *Star*, that is the Arch D O; for that Arch meaſures the Angle P Z A, from which, and the ſides P Z, P A, we may find Z A the true diſtance of the *Star* from the Vertex, from which ſubſtract Z C the obſerved Diſtance, and we ſhall have C A the Refraction required.

The Method of obſerving the Azimuth of a Star. Plate XIX. Fig. 6.

THE Azimuth of any *Star* is beſt obſerved, by drawing on the Plane of the Horizon the Meridian Line A E; upon which erect the Perpendicular C A, which is eaſily perform'd by a Line and a Plummet: Then take another Thread with a Weight as B D, and hang it ſo that the Body of the *Star* may be covered by the two Threads C A, D B, and then the *Star* will be in the Plane of a Vertical Circle, in which Plane the Threads do likewiſe ſtand: Mark then the Point B in the Plane of the Horizon, and in the Meridian Line the Point A, upon which is erected the Thread A C: And taking in the Meridian Line any Point E, draw A B, B E; then by the help of a Scale of equal parts meaſure the three ſides of the Triangle B A E, from which by *Trigonometry* we ſhall find the Angle B A E, which is the Azimuth that was to be found.

FROM Refraction, the reaſon is plain why the Sun and Moon near the Horizon appear of an oval Figure; for their inferiour Limbs are more refracted and raiſed higher than the ſuperiour Limbs are; and therefore theſe two Limbs will ſeem nearer to each other, and the breadth of the Bodies contracted, while both ends of the Horizontal Diameter being equally refracted and raiſed, keep the ſame diſtance from one another, and its apparent Magnitude remains the ſame.

When the Sun is in the Horizon its Rays paſs thorough a larger ſpace of Air than when he is in the Zenith.

Plate XIX. Fig. 7.

THE Rays of the Sun, when he is in or near the Horizon, paſs thorow a larger body of Air, than when he is near the Vertex. For let A B D be the Earth, E C F the Orb of Air which ſurrounds it, whoſe Altitude is commonly reckon'd to be 50 Miles. Let C A be an Horizontal Ray, E A a Vertical Ray: It is manifeſt that C A is longer than E A; and the proportion of theſe Lines may be thus found out. Suppoſe the Semidiameter of the Earth in round Numbers to be 4000 Miles, and E A 50; then is T E = C T 4050, whoſe Square is equal to the Squares of CA and A T: And therefore if from the Square of C T we take away the Square of TA, there will remain the Square CA; That is, if from 16402500 we ſubſtract 16000000, there will remain 402500, which is the Square of C A, whoſe Root is 634: And therefore C A : A E : : 634 : 50, which is greater than the proportion of 12 to 1. Hence

Plate XIX

front. p. 244

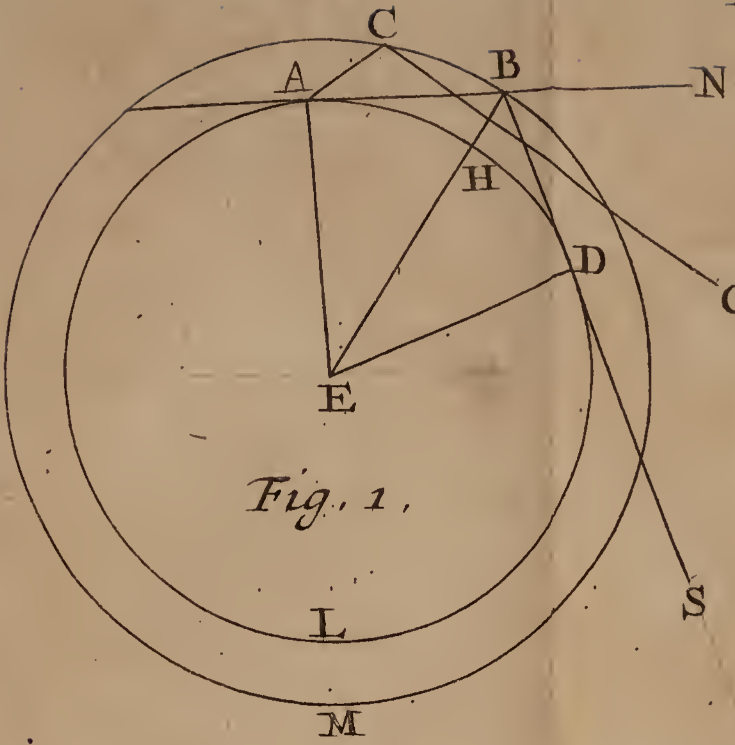


Fig. 1.

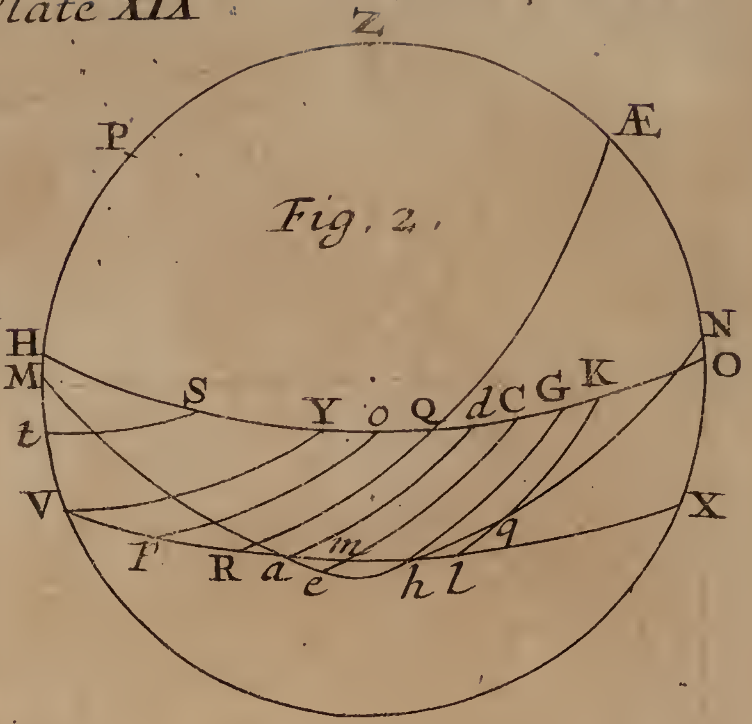


Fig. 2.

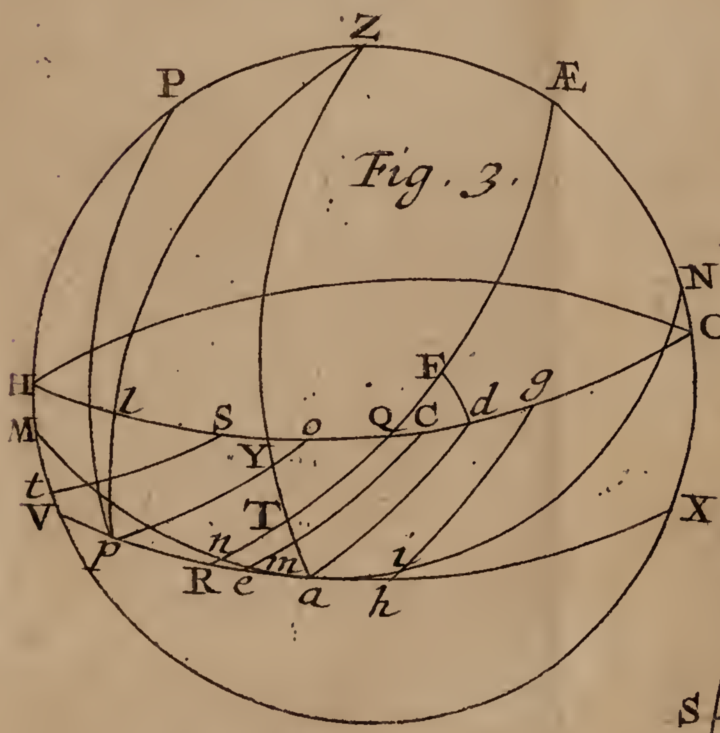


Fig. 3.

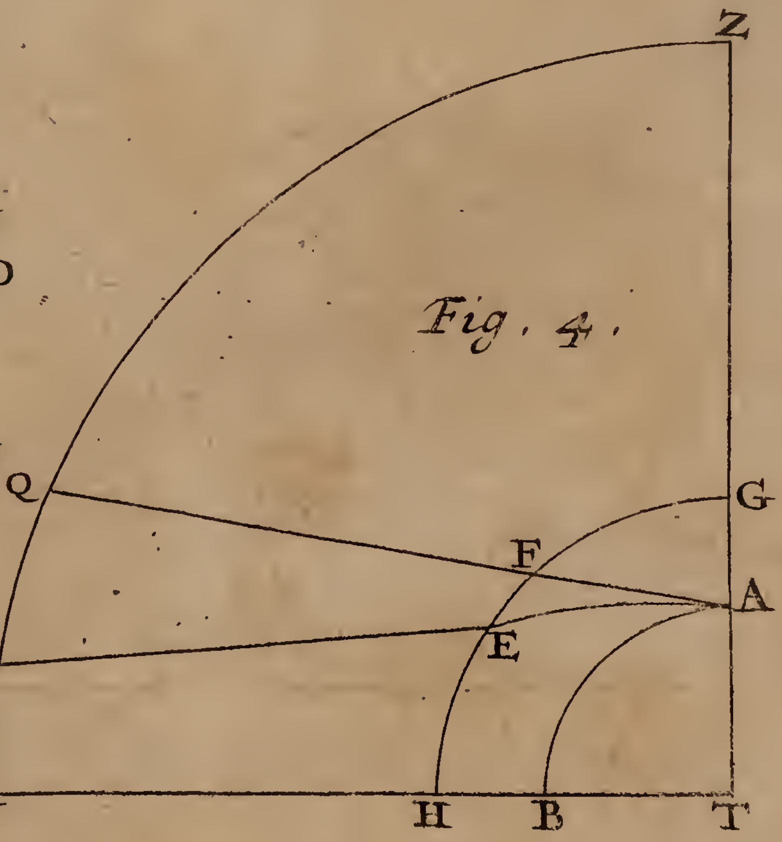


Fig. 4.

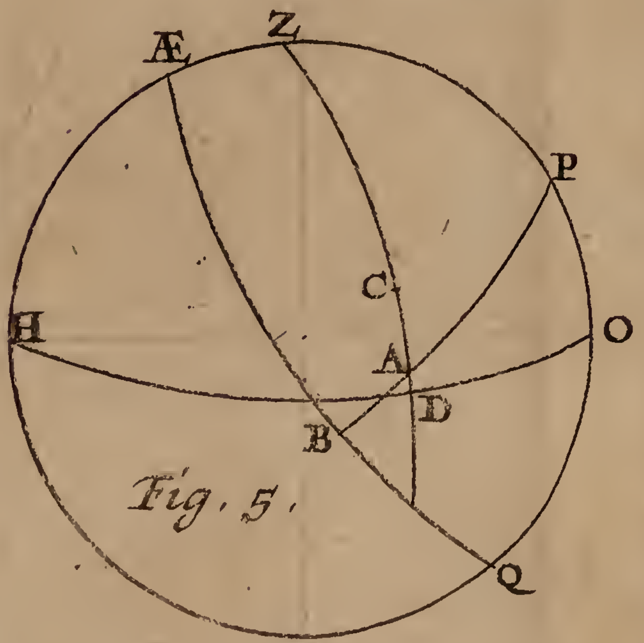


Fig. 5.

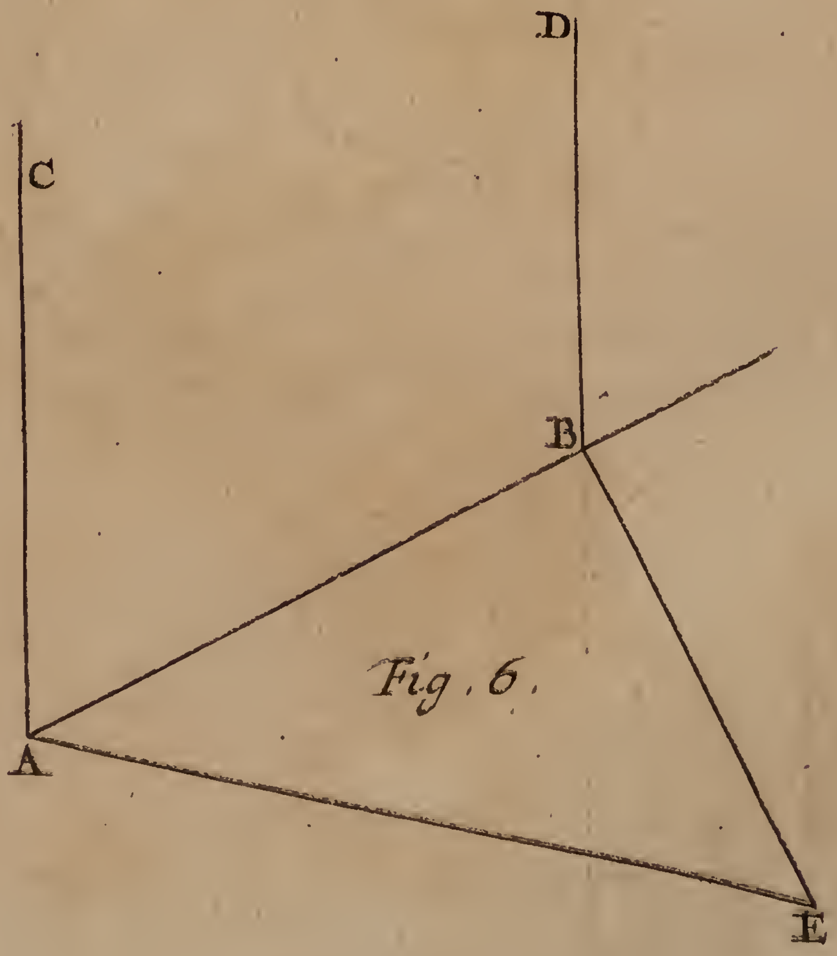


Fig. 6.

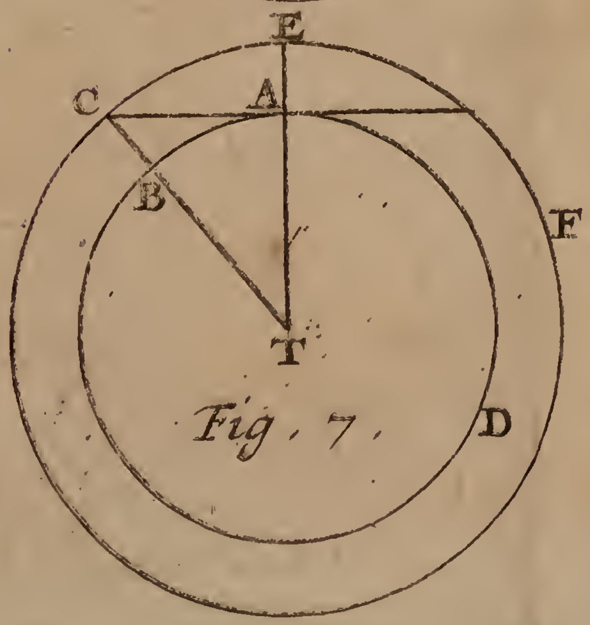


Fig. 7.

we ſee the reaſon why without hurting our Eyes, we can look upon the Sun at riſing and ſetting: But in the Meridian he is not to be looked upon without the danger of hurting our Sight. For the Rays of the Sun in the Horizon penetrating ſo large a body of Air, hit againſt an infinite number of Particles ſwimming in it, and being reflected or abſorbed, the force of the Light is thereby much weakned. Since therefore Light is ſo much weakned in paſſing thro' ſo ſmall a ſpace as our *Atmoſphere*; if this *Atmoſphere* were ſo large as to reach the Moon, and were of the ſame Denſity, neither Sun, Moon, nor Stars could then be ſeen.

LECTURE XXI.

Of the Parallaxes of the STARS.

SINCE all the apparent diurnal Motions are performed uniformly round the Axis of the Earth, and not round the place of the Spectator, who lives upon the Earth's Surface; he who obſerves the Motion of the *Stars* from this Surface, muſt find that they appear to move with a Motion that is not equal. For if a body by its Motion deſcribes equally the Periphery of a Circle, the equality of Motion can be ſeen from no other Points than thoſe in the Axis of this Circle. And therefore any *Star* or *Phænomenon* ſeen from the Center of the Earth will appear in a different Place from what it does when obſerved from the Surface; and this difference of Place of the ſame *Star*, ſeen from the Earth's Center and viewed from its Surface, is called the Parallax of that Star.

Table XX. Fig. 1.

LET A B be a quadrant of a great Circle on the Earth's Surface, where A is the place of the Spectator, and the point V in the Heavens his Vertex or Zenith. Let V N H repreſent the ſtarry Firmament, the Line A D the ſenſible Horizon, in which ſuppoſe the *Star* C to be ſeen, whoſe diſtance from the Center of the Earth is T C. If this *Star* were obſerved from the Center T, it would appear in the Firmament in E, and elevated above the Horizon by the Arch D E. This Point E is called the true Place of the *Phænomenon* or *Star*: But an Obſerver viewing it from the ſurface of the Earth at A, will obſerve its Place in the Horizon at D, which is called the viſible or apparent Place of the *Star*: And the Arch D E, the diſtance between the true and viſible Place, is named the *Parallax of the* Star.

IF the *Star* riſe higher above the Horizon to M, its true Place viſible from the Center is P, but its viſible Place from the ſurface is N, and its Parallax is the Arch P N, which is leſs than the Arch D E. And therefore the horizontal Parallax is greateſt of all Parallaxes; and the higher the *Star* riſes, the leſs is its Parallax: And if it ſhould come to the Vertex it would have no Parallax at all. For when it is in Q it is ſeen both from T and A in the ſame Line TAV, and there is no difference between its true and viſible Place. The further a *Star* is diſtant from the Earth, ſo much the leſs is its Parallax: So the Parallax of the *Star* F is G D, which is leſs than the Parallax of the nearer *Star* C. Hence it is plain that the Parallax is the Difference of the Diſtances of a *Star* from the Vertex, when ſeen from the Center and from the ſurface of the Earth. For the true diſtance of the *Star* M from the Vertex is the Arch V P; but when obſerved from A its viſible diſtance is V N.

THESE diſtances are meaſured by the Angles V T M and V A M, contained between the Line V T drawn to the Vertex, and the right Lines T M and A M drawn from the Center and the ſurface of the Earth to the *Star* M: But the difference of theſe two Angles is T M A. For the external Angle V A M is equal to the two inward and oppoſite Angles A T M and A M T: And therefore A T M is the difference of the two Angles V A M and A T M or V T M. This Angle AMT does therefore meaſure the Parallax, and upon that account itſelf is frequently called the Parallax: And this is always the Angle under which the Semidiameter of the Earth AT appears to an Eye placed in the *Star*: And therefore where this Semidiameter is ſeen directly, there the Parallax is greateſt, that is in the Horizon. When the *Star* riſes higher, the Parallax is diminiſhed in the proportion we ſhall ſhew in the following *Theorem*.

THE Sine of the Parallax is to the Sine of the Star's *diſtance from the Vertex in a conſtant and given proportion, which is as the Semidiameter of the Earth to the diſtance of the* Star *from the Earth's Center.*

FOR by a well-known Theorem in *Trigonometry*, in the Triangle A T M, the Sine of the Angle A M T is to the Sine of the Angle TA M or VA M, as A T is to T M; that is in the conſtant proportion of the Semidiameter of the Earth to the *Stars* diſtance. And therefore the Sine of the Parallax in C is to the Sine of the Parallax in M, as the Sine of the Angle VA C is to the Sine of the Angle VA M: And therefore if the Parallax of a *Star* be known when it is at any one diſtance from the Vertex, we can find its Parallax at any other diſtance from the Vertex. If any *Star* or *Phænomenon* be further diſtant from the Earth than 15000 Semidiameters of the Earth, its Parallax will be ſo ſmall that it will be inſenſible and cannot be obſerved: For ſince T F is to TA as 15000 to 1; and as T F is to TA, ſo is the Radius to the Sine of the Angle T F A. Hence we ſhall find the Angle T F A leſs than 14 Seconds, which Angle is ſo ſmall that it cannot be obſerved by any Inſtrument.

Lecture XXI.

IF we have the diſtance of a *Star* from the Earth, we can eaſily find its Parallax; for in the Triangle TAC rectangular at A, having TA the Semidiameter of the Earth, and TC the diſtance of the *Star*, the Angle ACT, which is the horizontal Parallax, is found by *Trigonometry*: And again, if we have this Parallax we can find the diſtance of the *Star*, for in the ſame Triangle having AT and the Angle ACT we may find out the diſtance TC.

IF a *Star* has no proper Motion of its own, its true diſtance from any Fixed *Star* meaſured by an Arch of a Circle always remains unchangeably the ſame: But if it have a ſenſible Parallax its apparent diſtance will be thereby changed; and if the Fixed *Star* be in the ſame vertical with the *Phænomenon*, but higher than it, the diſtance will appear to grow leſs as it riſes higher. If the *Star* be lower, as they aſcend the diſtance will encreaſe, yet ſeen from the Center they will appear conſtantly to keep the ſame diſtance from each other: And therefore the viſible diſtances of a *Phænomenon* from a Fixed *Star* which is near it, are not the real but apparent ones.

By the Parallaxes the diſtance of a Phænomenon *from the next Fixed Star is conſtantly variable.*

LET there be a *Phænomenon* or *Star* appearing in the Horizon in C: If it were obſerved from the Center, it would be ſeen in Conjunction with the Fix'd *Star* E. But the Spectator in A will ſee it in the ſame Line with the Star D, and will be diſtant from the *Star* E by the Arch DE. But as it riſes higher into M, it will ſtill appear from the Center of the Earth in Conjunction with the ſame *Star* E, which then will appear in P. But from the ſurface of the Earth in A it will appear in N, nearer to the *Star* E than it was when in the Horizon; and therefore will not appear in Conjunction with the ſame *Star* D, as it did before; but will be diſtant from it by the Arch N*d*, making the Arch P*d* equal to ED. Hence it follows, that if any *Phænomenon* always keeps the ſame Poſition in reſpect of the Fixed *Stars*, and changes not its arcual diſtances from them, it has no ſenſible Parallax. But even likewiſe if its diſtance from the *Stars* be changed, yet if that change be only ſo much as ariſes from its proper Motion, in that caſe likewiſe it will have no ſenſible Parallax. But if any *Phænomenon* departs further from a Fixed *Star*, or comes nearer to it than what it would do by its proper Motion, this difference of acceſs or receſs is the effect of a Parallax.

THE Parallax of a *Star* in a vertical Circle changes its place in regard to the other Circles of the Sphere; and makes its viſible Longitude, Latitude, and Right-Aſcenſion to be different from the true ones, which are ſeen from the Center: And from hence ariſe four other kinds of Parallaxes.

Plate XX. Fig. 2.

LET HO be the Horizon, whoſe Pole is V, EQ the Ecliptick and its Pole P, VA a vertical Circle paſſing thro' the *Star* whoſe true Place is C, but apparent Place D, in the ſame Vertical but nearer to the Horizon; ſo that the Parallax of Altitude is DC. Thro' the Pole of the Ecliptick and the Star draw the Circle of Latitude PCG, and G will be the true place of the Star reduced to the Ecliptick. But a Circle of Latitude thro' the apparent place D will meet with the Ecliptick in H, which will be the viſible or apparent place of the Star in the Ecliptick: The Arch of the Ecliptick GH intercepted between the two Circles of Latitude paſſing thro' the true and apparent place, is called the Parallax of Longitude, and CN the Parallax of Latitude.

The Parallax of Longitude.

IF the Star be in the vertical Circle which cuts the Ecliptick in the 90*th* Degree from the Horizon; *i. e.* in that Vertical which cuts the Ecliptick at Right-Angles; As for Example; In the Point *c* of the Circle VE, the Parallax of Longitude will be nothing. For becauſe the vertical Circle VE is in this caſe perpendicular to the Ecliptick, it will paſs thro' its Poles, and will be the ſame Circle of Latitude in which is the true and apparent place of the Star; and both theſe places reduced to the Ecliptick will coincide in the ſame Point: And here the Parallax of Latitude will be the ſame with the Parallax of Altitude.

The Parallax of Latitude.

THE Eaſtern Quadrant of the Ecliptick is that which lyes between the 90*th* Degree and the point of it that riſes: The Weſtern Quadrant lyes between the 90*th* Degree and the ſetting point thereof. A *Star* that is in the Eaſtern Quadrant has its apparent Longitude greater than its true Longitude; for while the *Star* riſes the Parallax depreſſes it towards the *Eaſt.* So in the *Fig.* the viſible place of the *Star* in the Ecliptick is the point H, which is more Eaſterly than the true place G: But if the *Star* be in the Weſtern Quadrant, its viſible Longitude is leſs than the true, becauſe the Parallax thruſts it Weſtward.

LET the Circle E Q, which before repreſented the Ecliptick, be now in the place of the Equator, and P its Pole, P V H the Meridian, V C A a vertical Circle paſſing through the *Star*, in which let C be its true place, and D its apparent. P C G, P D H Secondaries of the Equator or Circles of Declination paſſing thro' the true and apparent Places of the *Star*, meeting with the Equator in G and H. The point G ſhews the true Right Aſcenſion of the *Star*, H its apparent, and the diſtance G H is called the Parallax of Right-Aſcenſion. The true Declination of the *Star* is G C, and its viſible is H D, and their Difference N C is the Parallax of Declination. If a *Star* be to the *Eaſt* of the Meridian, the viſible Right-Aſcenſion is greater than the true; if to the *Weſt* of it, it is leſs: And when the *Star* culminates, the Parallax of Right-Aſcenſion is nothing, becauſe the ſame Circle of Declination does there paſs thro' both the apparent and true place.

THE *Aſtronomers* have invented ſeveral Methods for finding the Parallaxes of *Stars*, that from thence their diſtances from the Earth may be known; for if we knew this, we could make ſome Eſtimate of the Largeneſs and Amplitude of the Univerſe. Let us now give ſome of the Methods which the *Aſtronomers* have contrived for ſearching out the Parallaxes.

The firſt way of finding the Parallax.

Plate XX. Fig. 3.

FIRST obſerve the *Star* when it is in the ſame vertical Circle with two other Fixed *Stars*. Let V B be the vertical Circle in which are ſeen the Fixed *Stars* C and D, and the *Phænomenon* or *Star* S, whoſe apparent place will be likewiſe in the ſame Vertical, which ſuppoſe to be E; and if the *Star* have no proper Motion of its own, it will conſtantly be in the ſame Line with the two *Stars*: After ſome time, again obſerve the Poſition of the *Phænomenon* with the ſame *Stars*, when it is not in a vertical Circle with them, but rather in a Circle parallel to the Horizon; *i. e.* Suppoſe the Fixed *Stars* in *c* and *d*, and let the viſible place of the *Star* be *e*; but its true place is in the Line *c d* which joins the two Fixed. It is alſo in the Vertical V*e*; and therefore it muſt be in the point where theſe Lines cut one another, that is in S. Obſerve the diſtances of the Fixed *Stars* *d* and *c*, and of the *Star* *e* from the Vertex V: Meaſure likewiſe with an Inſtrument the Arches *d e*, *c e* and *d c*: And becauſe *e* is the apparent place of the *Star* and S its true place, the Arch *e* S is its Parallax. In the Triangle *d* V*c* we have all the ſides; wherefore we can find the Angle V *d c*: Again in the Triangle V *d e*, we have all the ſides, therefore we can find the Angle *d* V *e*. Laſtly, In the Triangle *d* V S we have the ſide *d* V, and the Angles *d* V S and V *d* S, which we found before; therefore we can find the ſide V S, which being ſubſtracted from V *e*, known by Obſervation, leaves S *e* for the Parallax, which was to be found out.

A Second Method.

Plate XX. Fig. 4.

THE Parallax of a *Star* may be likewiſe eaſily found this way. Obſerve when the *Phænomenon* is in any Vertical with a Fixed *Star* which is near it, and then meaſure its apparent diſtance from this *Star*: Then obſerve again when the *Phænomenon* and Fixed *Star* are in equal Altitudes from the Horizon; and then again meaſure their diſtance.

Lecture XXI. ſtance: The Difference of theſe Diſtances will be very near the Parallax of the *Star*. For let H O be the Horizon, V the Vertex, V E a vertical Circle paſſing through the *Star* in E, and the Fix'd *Star* in D. Let the true place of the *Phænomenon* be S, ſo that S E is the Parallax of Altitude, and the Difference of the *Star's* and the *Phænomenon's* height, is in this caſe their viſible diſtance. Afterwards obſerve when the *Star* and the *Phænomenon* comes to be equally diſtant from the Horizon, and then meaſure their diſtance by an Inſtrument: This viſible diſtance is nearly equal to their true diſtance. For let the true place of the *Phænomenon* be *s*; the Parallax *s e* is very ſmall in compariſon of the Arch V *e*: And therefore *d s* and *d e* will be very near equal; for if the Parallax *s e* were a whole Degree, yet even then *d s* and *d e* would not differ above one Minute: Therefore the diſtance *d e* being meaſured, we ſhall have their true diſtance *d s* or D S, which is greater than D E. And if from D S we ſubſtract DE, known by the firſt Obſervation, there will remain S E the Parallax, which was to be found.

The Third Method. THE Parallax of a *Phænomenon* may likewiſe be obtained by an Obſervation of its Azimuth and Altitude, and by marking the time between the Obſervation and its arrival at the Meridian. Let H V P O be the Meridian, V the Vertex, P the Pole, H O the Horizon, and V B a vertical Circle paſſing thro' the true and apparent place; thro' which draw alſo Circles of Declination P S C, P E. The Arch of the Horizon B O is the Azimuth of the *Star*, which muſt be obſerved, in the manner we ſhewed in our laſt *Lecture*. Obſerve likewiſe the Arch VE, the diſtance of the *Phænomenon* from the Vertex, and mark the Moment of Time when theſe Obſervations are made. Then ſtay till the *Phænomenon* or *Star* comes to the Meridian, and note the Moment of its arrival there, which may be either done by a Pendulum Clock, or by an Obſervation of a *Star*. Let Plate XX. Fig. 5.

the diſtance of Time between the firſt Obſervation and the ſecond of the *Stars* being in the Meridian, be converted into Degrees and Minutes of the Equator, and we ſhall have the Arch Æ C, which meaſures the Angle V P S. Therefore in the Triangle V P S we have the ſide V P the diſtance of the Vertex from the Pole, and the Angles P V S and V P S; whereby we can find the Arch V S the true diſtance of the *Phænomenon* from the Vertex: This being ſubſtracted from the obſerved diſtance V E, there will remain the Parallax S E, which was to be found.

IT is here to be noted, that for to reduce the Time into Degrees and Minutes of the Equator, that the Time muſt be firſt reduced into Hours and Minutes of the *Primum Mobile,* or to the Time of the Revolution of the Heavens, which Hours are ſomewhat ſhorter than the Solar Hours: Or if you keep the Solar Hours, you muſt reckon for each of them 15 Degrees, 2 Minutes, 27 Seconds, and 51 Thirds: And ſo proportionably for the reſt of the Particles of Time.

A Fourth Method.

SUPPOSE H O an Arch of the Horizon, A M the Meridian, in which P is the Pole, and V the Vertex of the place. Suppoſe E the apparent place of the *Star*; before the *Star* comes to the Meridian obſerve the Arch V E its diſtance from the Vertex, and its Azimuth E V M: Let the true place of the *Star* be S, its Parallax is S E: Mark the time of the Obſervation. Again, after the *Star* has paſſed the Meridian, obſerve when it is exactly at the ſame diſtances from the Vertex, ſo that V *e* may be equal to V E: And here, ſince the viſible diſtances of the *Star* from the Vertex are equal, the real diſtances will be likewiſe equal, *i. e.* V S = V *s*. Take the Time between the firſt and ſecond Obſervation and turn it into Degrees and Minutes of the Equator, and we ſhall have the Angle S P *s*, the half of which is the Angle S P V. Therefore in the Triangle S V P we have the Angle S P V, and the Angle S V P, which is the Complement of the Azimuth to two

Right-Angles; alſo the ſide VP the diſtance of the Pole and Vertex; from them we ſhall know VS the true diſtance of the *Star* from the Vertex, which being ſubſtracted from VE, leaves SE for the Parallax.

The Fifth Method. THESE Practices depend upon Obſervations of the Azimuths; but without obſerving them the Parallax may be known by finding out the apparent and true Right-Aſcenſions, and from them by Calculation finding the Azimuth: For by obſerving the diſtance of a *Phænomenon* from two known Fixed *Stars*, we can compute its apparent Right-Aſcenſion, according to the Method explained in *Lecture* XIX: Then again, when the *Star* comes to the Meridian, by the ſame Method find its Right-Aſcenſion, which is the true Right-Aſcenſion, or the point where the Circle of Declination paſſing thro' the true place of the *Star* cuts the Equator. Knowing then the apparent Right-Aſcenſion of the *Star* in the Vertical VB, and the point of the Equator which at the ſame time culminates, we ſhall likewiſe know the Angle VPE: Therefore in the Triangle VPE having the ſides VP, VE, and the Angle VPE, we can find the Angle PVE, which determines the Azimuth. But having the true Right-Aſcenſion of the *Star* as was obſerved in the Meridian, and the point of the Equator culminating at the firſt Obſervation, the diſtance between them will give us the Angle VPS. Therefore in the Triangle VPS having the two Angles VPS and SPV, as alſo the ſide VP, we can find the ſide VS the real diſtance of the *Star* from the Vertex; which ſubſtracted from VE leaves SE the Parallax, which was to be found. Plate XXI. Fig. 1.

IN determining the Right-Aſcenſions of the *Stars* we are not to rely too much, in ſo nice an Affair as the Parallax is, on a Pendulum Clock for determining the Time; for there the Error of one Second in numbering being made, will produce an Error of Right-Aſcenſion of 15 Seconds.

FOR to obſerve the Right-Aſcenſion of a *Star*, there is no need of ſtaying till it comes to the Meridian; but it is more eaſily and certainly had by two Obſervations, one made in the Eaſtern Quadrant, and the other in the Weſtern ſide of the Heavens; but both muſt be made when the *Star* is at the ſame height above the Horizon: For if we take the diſtance of the *Phænomenon* from two known Fixed *Stars* when it is in the Eaſtern Region, we ſhall by that means find its apparent Right-Aſcenſion, which is greater than the true, becauſe the Parallax depreſſes a *Star* more Eaſterly. Again, when the *Star* deſcends on the Weſtern ſide, and comes to the ſame height, let its diſtance be likewiſe obſerved from two Fixed *Stars*, and get from them its apparent Right-Aſcenſion, which is juſt as much leſs than the true, as the former exceeded it. And therefore if the Differences between the two apparent Right-Aſcenſions be halfed, and this half be added to the leaſt or ſubſtracted from the greateſt, we ſhall have the true Right-Aſcenſion or the point in the Equator, where it meets with the Circle of Declination paſſing thro' the *Star*, that is the point C. But from the Time of the Obſervation we have the point of the Equator which culminated at that Moment; and conſequently we have the Arch Æ C, and the Angle Æ P C meaſured by it: Therefore in the Triangle V P S, having the ſide V P, and the Angles V P S and P V S, we can find the ſide V S the true diſtance of the *Phænomenon* from the Vertex, which ſubducted from the apparent diſtance, there willremain S E the Parallax required

Table XXI. Fig. 5.

The Sixth Method.

The eaſieſt and beſt way of finding the Parallax of Right-Aſcenſion is by a Teleſcope, in whoſe *Focus* are four Threads croſſing one another at half Right-Angles, as we ſhewed in our XIX*th Lecture.* Directing this Teleſcope to the *Star* turn it conſtantly round, till its apparent diurnal Motion appear to be along the Thread A B; in which Poſition the Thread will repreſent a Portion of the Parallel which the *Phænomenon* de-

Table XXI. Fig. 2.

ſcribes; and the Thread C D cutting it at Right-Angles will repreſent a Horary Circle. Obſerve therefore the Time when the *Phænomenon* is ſeen in the Horary Circle. The Teleſcope remaining thus fixed and unmoved, obſerve the Time when any other *Star*, whoſe Right-Aſcenſion is known, comes to the ſame Horary Circle: The diſtance of Time between the Appulſe of the *Phænomenon* to the Horary Circle, and of the Fixed *Star* to the ſame Circle, being turned into Degrees and Minutes of the Equator will ſhew the Difference of Right-Aſcenſions of the *Star* and the *Phænomenon*. Again, when the *Star* comes to the Meridian obſerve it with the Teleſcope, and by the ſame Method find out its Right-Aſcenſion, which will be the true one; and by it we ſhall have the point of the Equator, where the Circle of Declination paſſing thro' the true place of the *Star* does cut the Equator. Having therefore the true Right-Aſcenſion and the apparent, we have their Difference or the Parallax of Right-Aſcenſion. And becauſe we have the apparent Right-Aſcenſion and the point of the Equator then culminating, we have the Arch of the Equator intercepted between them, which is the meaſure of the Angle V P E. Therefore in the Triangle V P E we have the ſides V P, P E, and the Angle V P E, whence we find the Angle P V E. From the Angle V P E take the Angle S P E the Parallax of Right-Aſcenſion, and we ſhall have the Angle V P S. Laſtly, In the Triangle V P S, having the Angles V P S and P V S, together with the ſide V P, we can from them find the ſide V S, the true diſtance of the *Star* from the Vertex, which being ſubducted from the apparent diſtance, leaves the Parallax that was to be found.

Table XXI. Fig. 1.

The Method of finding the Parallax when the Star *has a proper Motion of its own.*

IF the *Phænomenon* have a proper Motion of its own, its Right-Aſcenſion will conſtantly be changed by this Motion, unleſs it ſhould happen to move in ſome Circle of Declination: And therefore Care muſt be taken to determine the Change of Right-Aſcenſion that ariſes by the Motion of the *Star*; which is done by obſerving

Plate XX

front. p. 256

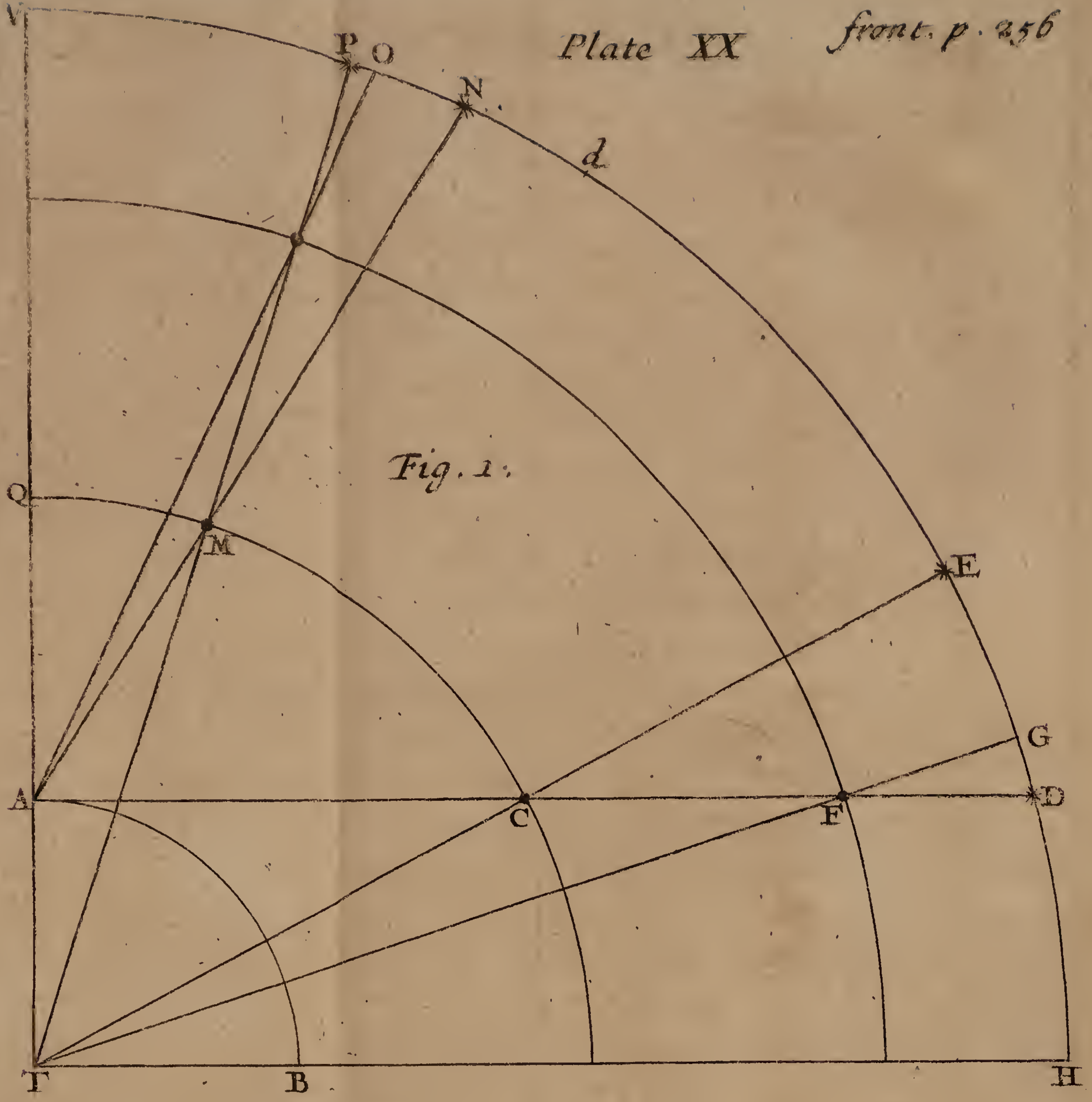


Fig. 1.

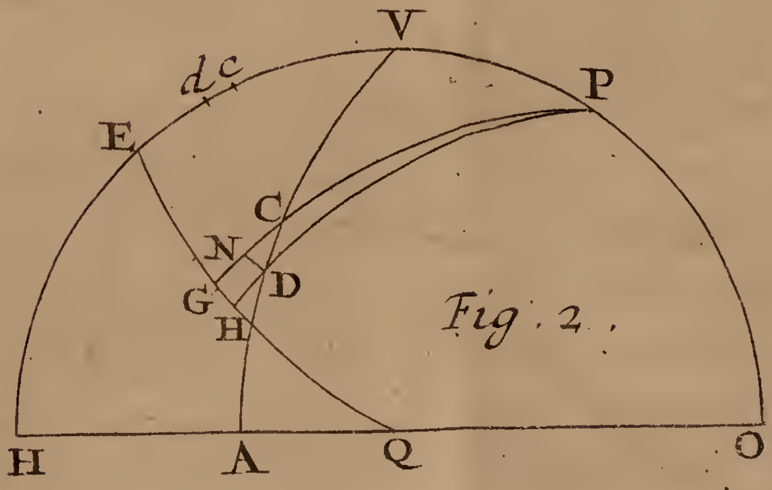


Fig. 2.

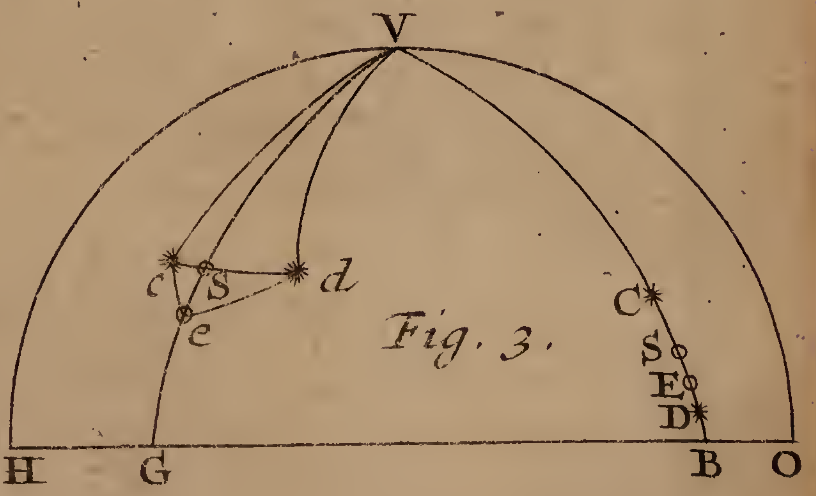


Fig. 3.

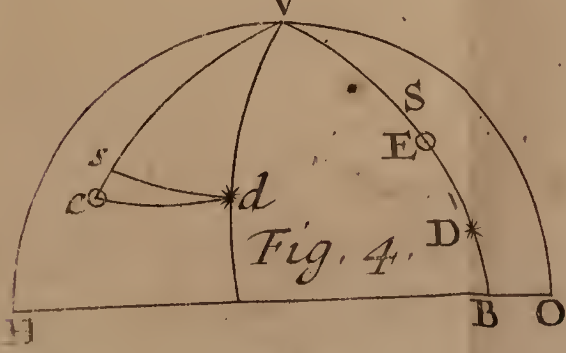


Fig. 4.

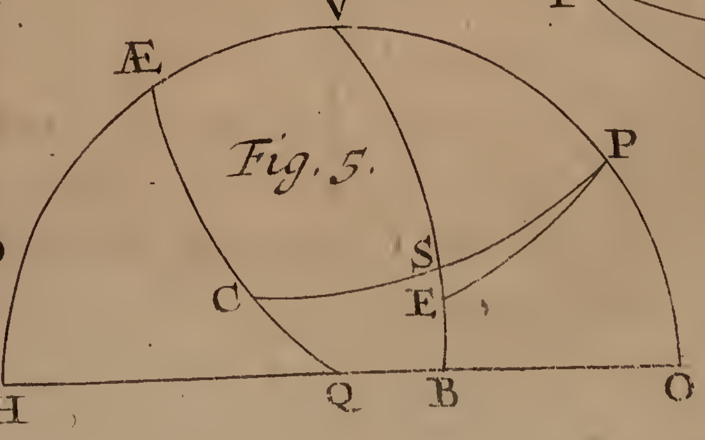


Fig. 5.

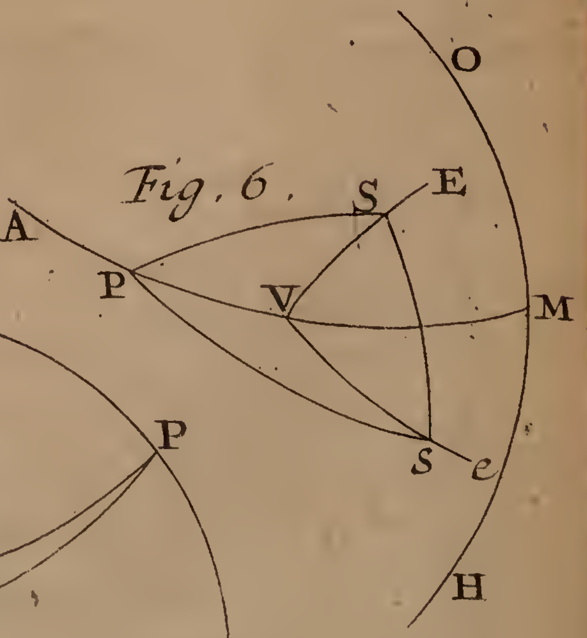


Fig. 6.

the Right-Aſcenſion of the *Star* when it is in the Meridian; and the next Day let its Right-Aſcenſion be in the ſame manner obſerved. The Difference of theſe Right-Aſcenſions will ſhew the Change that the Right-Aſcenſion has, for the Time between the two Obſervations: And from them we can find the Change of Right-Aſcenſion or the Motion of the *Phænomenon* along the Equator in a Day: From this diurnal Motion we can find by proportioning the Motion for any given Time. For Example, If the diurnal Motion according to the Equator be 30 Min. that is, ſuppoſe the *Phænomenon* advanced according to the Equator every Day 30 Minutes: And ſuppoſe the Time between the Obſervation on the Eaſtern ſide of the Heaven, and that in the Meridian be ſix Hours, the Motion according to the Equator in that time is 7 $\frac{1}{2}$ Minutes; let the Difference of Right-Aſcenſion obſerved in the Vertical and in the Meridian be 20 Minutes, Seven and a half of thoſe Minutes are owing to the proper Motion of the Body; wherefore the Parallax of Right-Aſcenſion is 12 $\frac{1}{2}$ Minutes.

AFTER the ſame manner by the apparent and real Longitude of a *Phænomenon* the Parallaxes may be inveſtigated. The apparent Longitude is found by obſerving the diſtance of a *Phænomenon* from two Fixed *Stars* whoſe Longitudes and Latitudes are known. And the true Longitude is had by making the ſame Obſervations when the *Star* is in the 90*th* Degree of the Ecliptick, where the apparent and true Longitudes coincide.

BY theſe and the like Methods if any *Phænomenon* has a Parallax not leſs than one Minute it may be found out. In the Moon we find the Parallax very conſiderable, which in the Horizon amounts to about a Degree or more. But there are ſome particular Methods only applicable to the Moon, by which its Parallax is known.

A Method for obſerving the Parallax of the Moon.

IN an Eclipſe of the Moon obſerve when both its Horns are in the ſame vertical Circle, and then in that Moment take the Altitudes of both

Lecture XXI.

Horns: The Difference of theſe two Altitudes being halfed and added to the leaſt, or ſubſtracted from the greateſt, does give nearly the viſible Altitude of the Moon's Center: But the true Altitude is nearly equal to the Altitude of the Center of the Shadow at that time. Now we know the Altitude of the Center of the Shadow, becauſe we know the place of the Sun in the Ecliptick, and its Depreſſion under the Horizon, which is equal to the Altitude of the oppoſite point of the Ecliptick, in which is the Center of the Shadow. And therefore we have the true Altitude of the Moon and the apparent Altitude, whoſe difference is the Parallax, which will therefore be known.

Tables of the Moon's Parallaxes.

AS the diſtance of the Moon grows leſs, according as it recedes from its *Apogæum*, her Parallax muſt in the ſame proportion be encreaſed, conſtantly the nearer ſhe comes to us. Therefore the Artiſts make Tables which ſhew the horizontal Parallax for every Degree of its Anomaly.

THE Methods we have given for finding the Parallaxes ſhew that the Moon has a great Parallax, and is very near us; but none of them is ſufficient for finding out the Parallax of the Sun: For that is ſo ſmall, that the Obſervations requiſite cannot be made accurately enough for to determine it; for an Error in obſerving can ſcarcely be avoided, which is not equal or greater than the Sun's Parallax. This defect of Obſervations put the Antient *Aſtronomers* on the ſearch of other Methods peculiar to the Sun for finding out its Parallax: But even thoſe Methods, though they make manifeſt the Acuteneſs and Sagacity of the Antients, yet are not ſufficient in ſo nice and ſubtle a Diſquiſition. However, they are uſeful to ſhew that the diſtance of the Sun from the Earth is very great in compariſon of the Moon's diſtance from the ſame: And therefore it will not be unfitting to explain them in this place.

Hipparchus's *Method for the Parallax of the Sun.*

THE firſt Method was invented by *Hipparchus*, and has been made uſe of by *Ptolemy* and his Followers, and many other *Aſtronomers*. It depends on an Obſervation of an Eclipſe of the Moon: And the Principles on which it is founded are, *Firſt*, In a Lunar Eclipſe the horizontal Parallax of the Sun is equal to the difference between the apparent Semidiameter of the Sun and half the Angle of the Conical Shadow; which is eaſily made out in this manner. Let the Circle A F G repreſent the Sun and D H E the *Earth*; let D H M be the Shadow and D M C the half Angle of the Cone. Draw from the Center of the Sun the Right-Line S D touching the Earth, and the Angle D S C is the apparent Semidiameter of the Earth ſeen from the Sun, which is equal to the horizontal Parallax of the Sun; the Angle A D S is the apparent Semidiameter of the Sun ſeen from the Earth: The external Angle A D S is equal to the two internals D M S and D S M, by the 32*d Prop.* Elem. I. And therefore the Angle D S M or D S C is equal to the Difference of the Angles A D S and D M S. 2*dly*, Half the Angle of the Cone is equal to the difference of the horizontal Parallax of the Moon and the apparent Semidiameter of the Shadow, ſeen from the Earth at the diſtance of the Moon. For let CDE be the Earth, C M E the Shadow, which at the diſtance of the Moon being cut by a Plane, the Section will be the Circle F L H, whoſe Semidiameter is F G, and is ſeen from the Center of the Earth under the Angle F T G. But by the 32*d Prop.* Elem. I. the Angle C F T is equal to the two internals F M T and F T M. Wherefore the Angle F M T is the difference of the two Angles C F T and G T F: But the Angle C F T is the Angle under which the Semidiameter of the Earth is ſeen from the Moon, and this is equal to the horizontal Parallax of the Moon; and the Angle G T F is the apparent Semidiameter of the Shadow ſeen from the Earth's Center. It is therefore evident that the half Angle of the Cone is equal to the difference of the horizontal Parallax of the Moon and the apparent Semidiameter of the Shadow ſeen from the Earth. Wherefore if to the apparent Semidiameter of the Sun

Lecture XXI.

Plate XXI. Fig. 3.

Plate XXI. Fig. 4.

Sun there be added the apparent Semidiameter of the Shadow, and from the ſum you take away the horizontal Parallax of the Moon, there will remain the horizontal Parallax of the Sun; which therefore if theſe were accurately known, would be likewiſe known accurately: But none of them can be ſo exactly and nicely obtained as to be ſufficient for determining the Parallax of the Sun; for very ſmall Errors which cannot be eaſily avoided in meaſuring theſe Angles, will produce very great Errors in the Parallax; and there will be a prodigious difference in the diſtances of the Sun when drawn from theſe Parallaxes. For Example, Suppoſe the horizontal Parallax of the Moon to be 60′. 15″, the Semidiameter of the Sun 16′, and the Semidiameter of the Shadow 44′. 30″; we ſhould conclude from thence that the Parallax of the Sun was 15″, and his diſtance from the Earth about 13700 Semidiameters of the Earth. But if there be an Error committed, in determining the Semidiameter of the Shadow, of 12″ in defect, (and certainly the Semidiameter of the Shadow cannot be had ſo preciſely as not to be liable to ſuch an Error) that is, if inſtead of 44′. 30″ we put 44′. 18″ for the apparent Diameter of the Shadow, all the others remaining as before, we ſhall have the Parallax of the Sun 3″, and its diſtance from the Earth almoſt 70000 Semidiameters of the Earth, which is five Times more than what it was by the firſt Poſition. But if the fault were in exceſs, or the Diameter of the Shadow exceeded the true by 12″; ſo that we ſhould put it 44′. 42″, the Parallax would ariſe to 27″, and the diſtance of the Sun only 7700 of the Earth's Semidiameter; which is nine times leſs than what it comes to by a like Error in defect. If an Error in defect was committed of 15″, which is ſtill but a ſmall Miſtake, the Sun's Parallax would be equal to nothing, and his diſtance infinite. Wherefore ſince from ſo ſmall Miſtakes the Parallax and diſtance of the Sun vary ſo much, it is plain that the diſtance of the Sun cannot be obtained by this Method.

Hipparchus's *Method inſufficient.*

SINCE therefore the Angle that the Earth's Semidiameter ſubtends at the Sun is ſo ſmall, that it cannot be determined by any Obſervation; *Ariſtarchus Samius*, an Antient and great *Philoſopher* and *Aſtronomer*, contrived a very ingenious way for finding the Angle which the Semidiameter of the Moon's Orbit ſubtends when ſeen from the Sun: This Angle is about ſixty times bigger than the former ſubtended only by the Earth's Semidiameter. For to find this Angle, he lays down the following Principles.

Ariſtarchus's *Method for the Sun's diſtance.*

IN that *Lecture* where we explained the *Phaſes* of the Moon, we ſhewed that if a Plane paſſed thro' the Moon's Center, to which the Line joyning the Sun and Moon's Center was perpendicular, this Plane would divide the illuminated Hemiſphere of the Moon from the dark one: And therefore if this Plane ſhould likewiſe paſs thro' the Eye of a Spectator on the Earth, the Moon would appear biſected or like a half Circle; and a Right Line drawn from the Earth to the Center of the Moon would be in the Plane of Illumination, and conſequently would be perpendicular to the Right-Line which joins the Centers of the Sun and Moon. Let S be the Sun and T the Earth, A L q a Quadrant of the Moon's Orbit; and let the Line S L drawn from the Sun touch the Orbit of the Moon in L; the Angle T L S will be a Right-Angle: And therefore when the Moon is ſeen in L it will appear biſected or juſt half a Circle. At the ſame time take the Angle L T S the Elongation of the Moon from the Sun, and then we ſhall have the Angle L S T its Complement to a Right-Angle. But we have the ſide T L, by which we can find the ſide S T, the diſtance of the Sun from the Earth.

Table XXI. Fig. 5.

BUT the difficult point is to determine exactly the Moment of Time when the Moon is biſected, or in its true *Dichotomy*; for there is a conſiderable ſpace of Time both before and after the *Dichotomy*; nay, even in the Quadrature, when the Moon will appear biſected or half a Circle; ſo

Ariſtarchus's *Method inſufficient.*

ſo that the exact Moment of Biſection cannot be known by Obſervation, as Experience tells us: This can be alſo made out by the following reaſon. In the *Lecture* concerning the *Phaſes* of the Moon, it was demonſtrated that the Diameter of the Earth was to the Portion of it illuſtrated by the Sun, and ſeen by us, as the Diameter of a Circle is to the *Verſed Sine* of the Elongation of the Moon from the Sun, nearly: But accurately it is as the Diameter of a Circle to the *Verſed Sine* of the exterior Angle at the Moon, of the Triangle formed by Lines joining the Centers of the Sun, Earth and Moon, as we ſhewed in the *Lecture* concerning the *Phaſes* of *Venus*. Let us ſuppoſe in the time of true *Dichotomy* or Biſection, that the Angle L S T is 15′, and that the Semidiameter of the Lunar Orbit were 60 Semidiameters of the Earth; the diſtance of the Sun would in that Caſe be 13758 of the Earth's Semidiameters. This being ſuppoſed, let us imagine the Moon to be in her Quadrature at *q*; that is, let the Angle *q* T S be a Right-Angle, the exterior Angle of the Triangle *q* T S at *q* would be 90°. 15′, whoſe *Verſed Sine* is equal to the Radius and the Right Sine of 15′ together: Therefore as the Diameter of a Circle is to the Radius + Sine 15′; ſo is the Diameter of the Moon to that part of it which is illuſtrated by the Sun, and ſeen from the Earth. Wherefore taking half the Antecedents, and by Diviſion of Ratio, the Radius will be to the Right Sine of 15′, as is the Semidiameter of the Moon to that exceſs, wherewith the illuminated part ſeen from the Earth is greater than half the Moon's Diameter. Now the Sine of 15′ is 436, of ſuch parts as the Radius is 100000, and the apparent Semidiameter of the Moon is about 15′: Say therefore, as 100000 is to 436, ſo is 15′ to a fourth, which is leſs than 4″; but this is ſo ſmall a Quantity, that it is not in the leaſt to be perceived by our Senſes: And therefore the Moon, even in the Quadratures, has its Illumination exceeding the biſected Illumination by ſuch a quantity as is altogether imperceptible: But if the real *Dichotomy* or Biſection were in the Quadrature, the diſtance of the Sun would be in Infinite; for in that caſe the Angles S T q and S q T being right, the Lines S T and S q would be parallel, and would not meet but at an infinite diſtance.

2*dly*, SUPPOSE the Elongation of the Moon from the Sun 89°. 30′: In that caſe the exterior Angle at the Moon is 89°. 45′, and its *Verſed Sine* equal to the Radius bating the Right Sine of 15′. And becauſe as the Radius is to the *Verſed Sine* of the exterior Angle, that is, to the Radius diminiſhed by the Sine of 15′; ſo is the Semidiameter of the Moon to that part of it which is illuſtrated and ſeen by us; then by Diviſion of *Ratio*, the Radius will be to the Sine of 15′; as is the Moon's Semidiameter to that part whereby the Semidiameter of the Moon is greater than the illuminated part thereof which is ſeen by us; which therefore (as in the former Caſe) will be ſcarce 4″: Now the Moon wanting but ſo ſmall a portion to be intirely biſected, will appear to us as if ſhe were really biſected; ſo that its *Phaſis* can in no wiſe be diſtinguiſhed from the true *Phaſis* of a *Dichotomy*: And therefore if this apparent *Phaſis* ſhould be taken for the true *Phaſis* of the *Dichotomy*, which is half a Degree diſtant from the Quadrature, we ſhould find the diſtance of the Sun from us to be 6876 Semidiameters of the Earth.

OBSERVATIONS inform us, that when the Moon is 30 Min. diſtant from the Quadratures it appears biſected; and in the Quadrature its *Phaſis* cannot be perceived to be different from a biſected *Phaſis*: Nay, the Moon obſerved with the beſt Teleſcopes, after it has paſt the Quadratures, appears biſected, as *Ricciolus* himſelf acknowledges in his *Almageſt*, p. 734. And therefore the Moon, at leaſt for the ſpace of one Hour, appears to be biſected, in which time any Moment may be taken for the true point of the *Dichotomy*, as well as any other: And for the infinite Number of Moments of Time, we ſhall have an infinite diverſity of Diſtances of the Sun from the Earth: And conſequently the true diſtance of the Sun from the Earth cannot be obtained by this Method.

SINCE the Moment in which the true *Dichotomy* happens is uncertain, but it is certain that it happens before the Quadrature; *Ricciolus* takes that point of Time which is in the middle, between the Time that the *Phaſis* begins to be doubtful whether it be biſected or not, and the Time of Quadrature: But he had done righter, if he had taken the middle point between the Time, when it becomes doubtful whether the Moon's ſide is concave or ſtreight, and the Time again when it is doubtful whether it is ſtreight or convex; which point of Time is after the Quadrature: And if he had done this, he would have found the Sun's diſtance a great deal bigger than he has made it.

There is no need to confine this Method to the Phaſis *of a Biſection.*

THERE is now no need to confine this Method to the *Phaſis* of a *Dichotomy* or Biſection, for it can be as well perform'd when the Moon has any other *Phaſis* bigger or leſs than a *Dichotomy*: For obſerve by a very good Teleſcope with a Micrometer the *Phaſis* of the Moon, that is, the proportion of the illuminated part of the Diameter to the whole; and at the ſame Moment of Time take her Elongation from the Sun: The illuſtrated part of the Diameter, if it be leſs than the Semidiameter, is to be ſubducted from the Semidiameter; but if it be greater, the Semidiameter is to be ſubducted from it, and mark the reſidue: Then ſay, as the Semidiameter of the Moon is to the reſidue, ſo is the Radius to the Sine of an Angle, which is therefore found: This Angle added to, or ſubſtracted from a Right-Angle, gives the exterior Angle of the Triangle at the Moon: But we have the Angle at the Earth, which is the Elongation obſerved; which therefore being ſubducted from the exterior Angle, leaves the Angle at the Sun. And in the Triangle S L T, having all the Angles and one ſide L T, we can find the other ſide S T, the diſtance of the Sun from the Earth. But it is almoſt impoſſible to determine accurately the Quantity of the Lunar *Phaſis*, ſo that there may not be an Error of a few Seconds committed; and conſequently we cannot by this Method find preciſely enough the true diſtance of the Sun. However, from ſuch Obſervations we are ſure that the Sun is above 7000 Semidiameters of the Earth diſtant from us. Since therefore the true diſtance of the Sun can neither be found by Eclipſes, nor by the *Phaſes* of the Moon, the *Aſtronomers* are forced to have recourſe to the Parallaxes of the Planets that are next to us, as *Mars* and *Venus*, that are ſometimes much nearer to us than the Sun is: Their Parallaxes they endeavour to find by ſome of the Methods above explained: And if theſe Parallaxes were known, then the Parallax and diſtance of the Sun, which cannot directly by any Obſervations be attained, would eaſily be deduced from them. For from the Theory of the Motions of the Earth and Planets, we know at any time the proportion of the diſtances of the Sun and Planets from us; and the horizontal Parallaxes are in a reciprocal Proportion to theſe diſtances. Wherefore knowing the Parallax of a Planet, we may from thence find the Parallax of the Sun.

The Sun's diſtance and Parallax may be deduced from the Parallax of the Planets.

Particularly by Mars *in an Acronychal Poſition.*

MARS, when he is an Acronychal Poſition, that is, oppoſite to the Sun, is twice as near to us as the Sun is; and therefore his Parallax will be twice as great. But *Venus* when ſhe is in her inferior Conjunction with the Sun, is four-times nearer to us than he is, and her Parallax is greater in the ſame proportion: Therefore, tho' the extream ſmalneſs of the Sun's Parallax renders it unobſervable by our Senſes, yet the Parallaxes of *Mars* or *Venus* which are twice or four-times greater, may become ſenſible. The *Aſtronomers* have beſtowed much Pains in finding out the Parallax of *Mars*; but of late *Mars* was in his Oppoſition

Lecture XXI.

to the Sun, and alſo in his *Perihelion*, and conſequently in his neareſt approach to the Earth: And then he was moſt accurately obſerv'd by two of the moſt eminent *Aſtronomers* of our Age, who have determined his Parallax to have been ſcarce 30 Seconds; from whence we can eaſily collect that the Parallax of the Sun is ſcarce 11 Seconds, and his diſtance about 19000 Semidiameters of the Earth.

The Parallax of the Sun found by obſerving Venus *in the body of the Sun.*

BY an Obſervation of the Body of *Venus* ſeen paſſing over the Body of the Sun, which will happen in *May* 1761, Dr. *Halley* has ſhewed a Method of finding the Parallax and Diſtance of the Sun to a great nicety, *viz.* within a five hundredth part of the whole; and we muſt wait till then before it can be determin'd to ſo great an exactneſs.

BECAUSE the Method whereby the *Aſtronomers* foretel Eclipſes of the Sun requires that the Moon's Parallax both as to Longitude and Latitude ſhould be known by Calculation: And alſo as often as the Moon's place in the Heavens is to be obſerved, that it may be compared to the place found out by *Aſtronomical* Tables, in order to eſtabliſh her Theory, it will be neceſſary to reduce the true place found by the Tables to her apparent place, which cannot be done without the Calculation of the Parallax: It will be convenient to explain the Method by which the Moon's Parallax for any point of Time is to be calculated.

How the Moon's Parallax is to be found for any time by Calculation.

Table XXI. Fig. 6.

FIRST, by *Aſtronomical* Tables compute the place of the Moon in the Eclipticks and her Latitude, for the given Time. In the Figure ſuppoſe H O the Horizon, H Z O the Meridian, Z the Vertex, E C the Ecliptick, in which let L be the place of the Moon, found by the Tables. And firſt, let us ſuppoſe the Moon to be without Latitude. From the Vertex Z let fall upon the Ecliptick the perpendicular Z *n* A; which will be therefore a Circle of Latitude; And the point *n* will be the 90*th* Degree of the Ecliptick. From the Time given we have the Right-Aſcenſion of the

Sun, and his Equatorial diſtance from the Meridian: From thence we ſhall find the point of the Equator culminating, which is the Right-Aſcenſion of Mid-Heaven, or of that point of the Ecliptick which culminates: And therefore we know that point which is then in the Meridian, as alſo the Angle Z E N of the Ecliptick and Meridian. This is either found by the Calculation we explained in the ſpherical Doctrine, or by Tables of *Aſtronomy*: By this means we find the Arch E L; but we have the Arch E Æ the Declination of the point E, and conſequently the Arch Z E will be known. Therefore in the Right-angled Triangle Z *n* E, we have the ſide Z E and the Angle Z E *n*. Hence we can find E *n* and the point *n* or the point of the 90*th* Degree, and the Arch Z *n* its diſtance from the Vertex; whoſe Complement *n* A is the meaſure of the Angle that the Horizon and the Ecliptick make: And becauſe we have the place of the Moon we muſt have the Arch *n* L. Therefore in the Right-angled Triangle Z *n* L, having the ſides Z *n* and *n* L, we ſhall have from them the Angle Z L *n*, which is called the *Parallactick Angle*, as likewiſe the ſide Z L, the diſtance of the Moon from the Vertex. Let the Radius be to the Sine of the Arch Z L, as the horizontal Parallax of the Moon taken from the Tables to its Parallax in L, which therefore is found. Let it be *o* L. From *o* on the Ecliptick let fall the Perpendicular *o m*. And in the Triangle *o* L *m* (which being very ſmall, may be taken for a rectilinear one) we have beſides the Right-Angle, the ſide L *o* and the Angle *o* L *m* equal to Z L *n*; wherefore we ſhall find out the Arch L *m* the Parallax of Longitude, and *o m* the Parallax of Latitude, which were to be found.

The Parallactick Angle.

SUPPOSE now the Moon has ſome Latitude, and its place in the Ecliptick be the point L, but let it be placed in the Circle of Latitude L P at P. And becauſe the Angle *n* L P is right, and we have the Angle *n* L Z and its Complement

Lecture XXI.

ment ZLP; In the Triangle ZLP we have two ſides, ZL which was found before, and LP the Moon's Latitude, and the Angle ZLP, whereby we can find out the ſide ZP, and the Angle ZPL. Let the Radius be to the Sine of the Arch ZP, as the horizontal Parallax of the Moon to a fourth, which will be P*q*: This will be the Parallax of the Moon in the Circle of Altitude. Let *q d* be an Arch parallel to the Ecliptick; and in the ſmall Triangle P*dq*, which may be taken as a Right-angled Triangle, we have the Angle *d*P*q*, which is the Complement of the Angle ZPL to two Right-Angles, and the ſide P*q*: Therefore we ſhall have P*d* the Parallax of Latitude, and *q d* the Parallax of Longitude: For becauſe the Latitude of the Moon is but ſmall, the Arch of the Parallel *d q* is nearly equal to the Arch of the Ecliptick which is correſpondent to it.

* * *

LECTURE XXII.

The Theory of the Annual Motion of the EARTH.

HITHERTO we have given an Account of the general Affections of the Planets Motions, and have explained the Appearances which ariſe from their Motions and the Motions of the *Earth* together. We will now come to their particular Theories, in which the Period of each, its Diſtance from the Sun, the Form of its Orbit, and its Poſition are determined; which being once known,

Plate XXI

front. p. 260

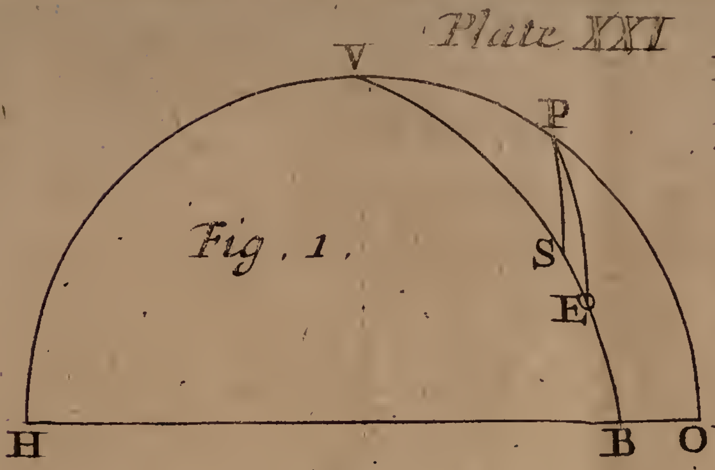


Fig. 1.

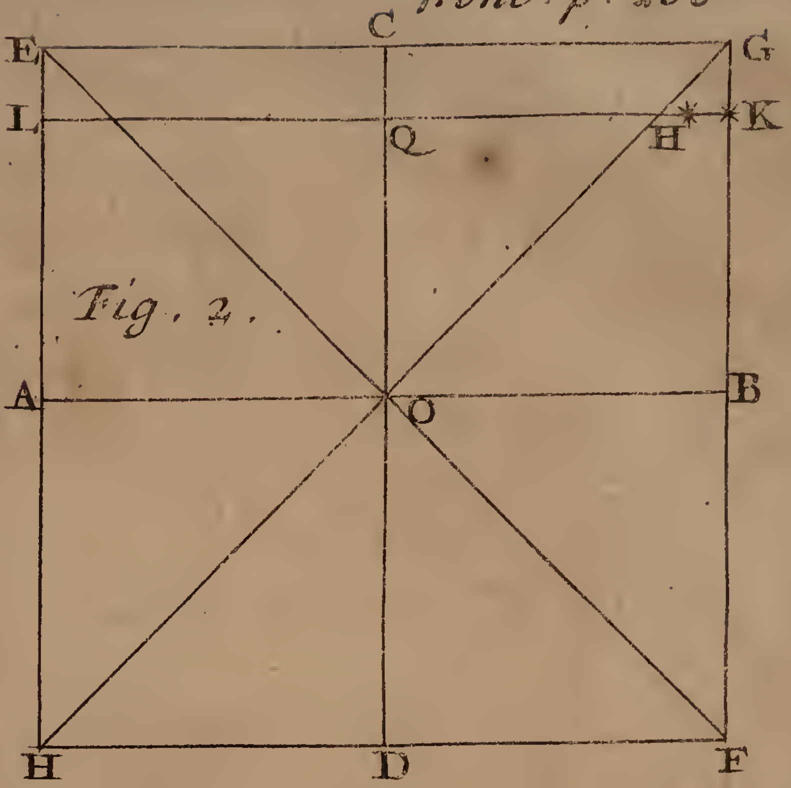


Fig. 2.

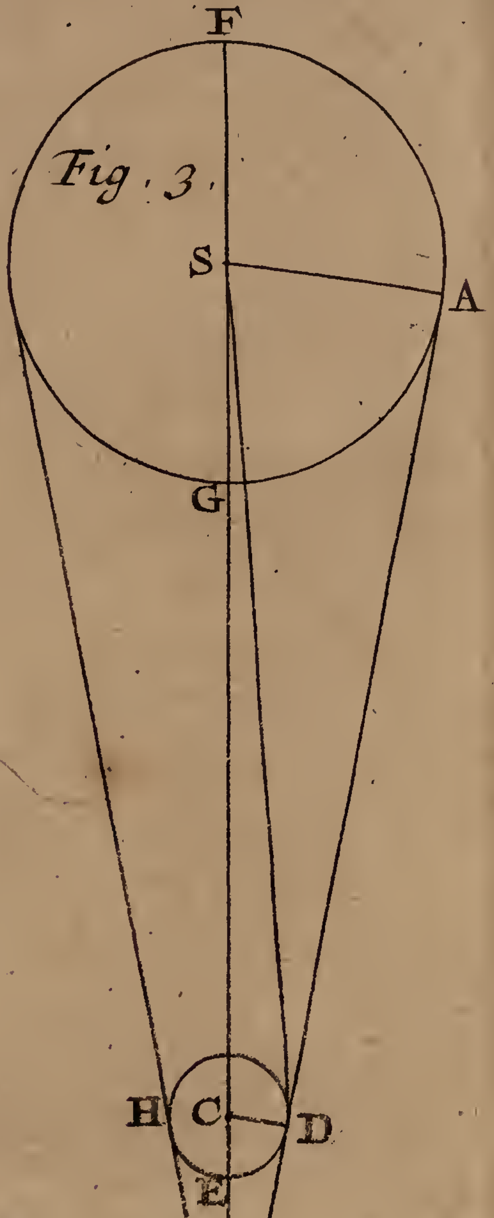


Fig. 3.

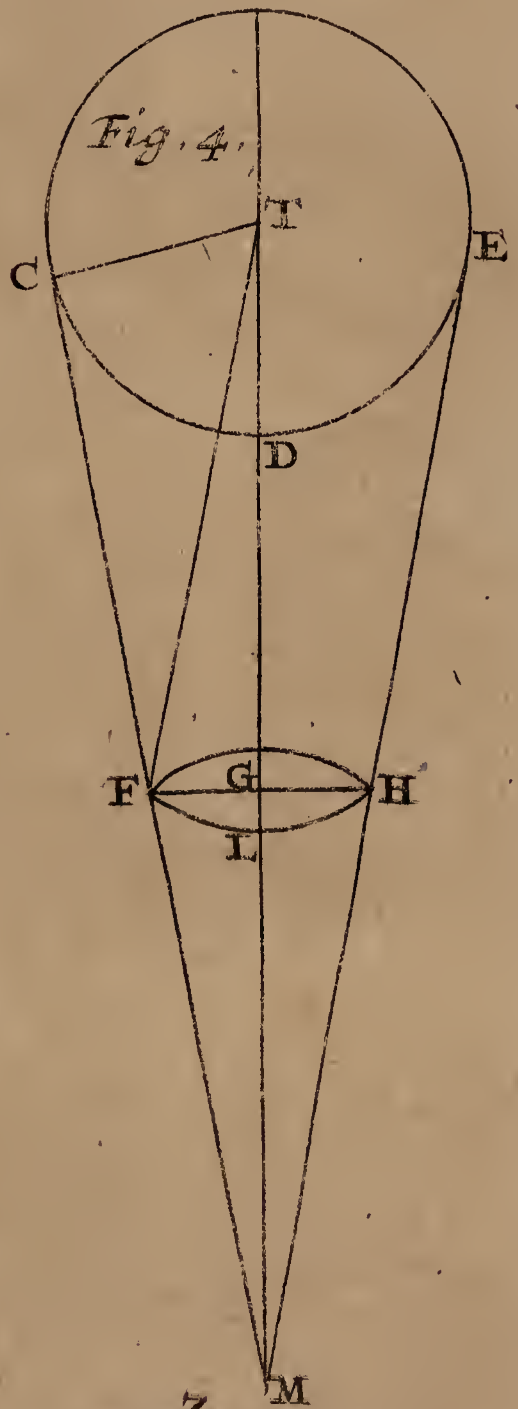


Fig. 4.

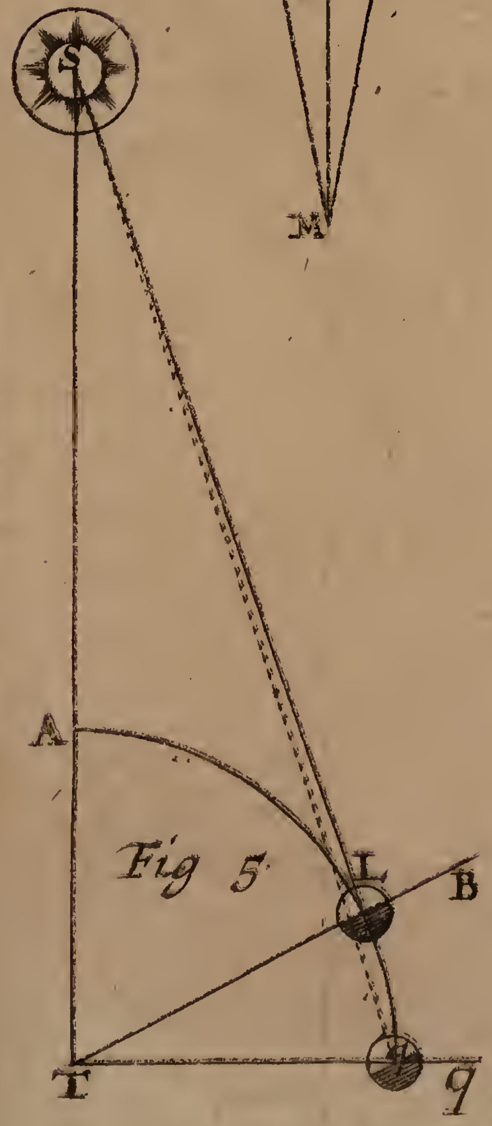


Fig 5.

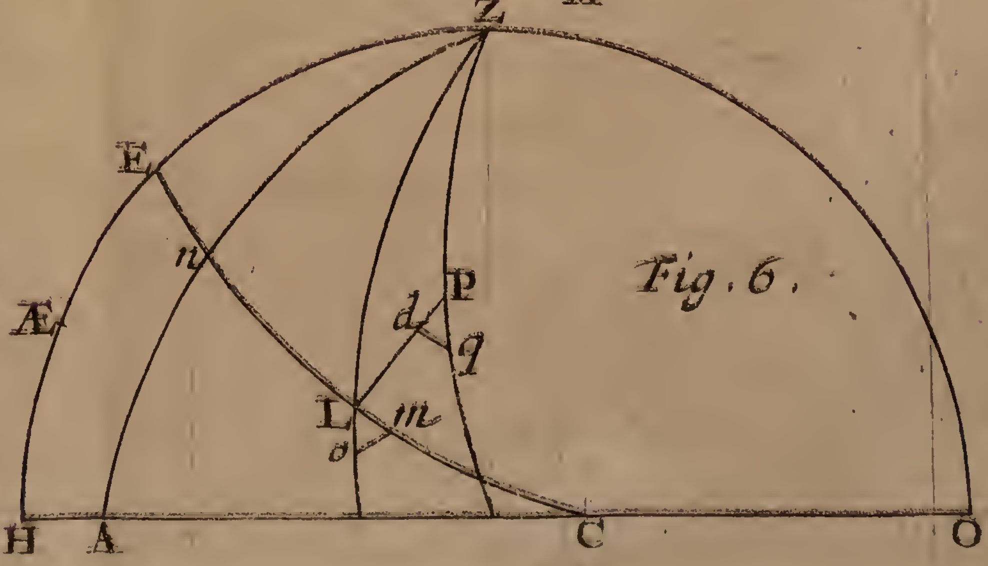


Fig. 6.

known, the Place of any Planet in the *Zodiack* may be computed for any given Time. And becauſe the Theories of the Planets are founded on the Motion of the *Earth*, and are inveſtigated by this Motion, it will be neceſſary to begin with the Theory of the *Earth*.

The Motion of the Earth *found by obſerving the Motion of the Sun.*

IN our VII*th Lecture* we ſhewed how the Motion of the *Earth* round the Sun was the cauſe of the Appearance of the annual Motion of the Sun in the Ecliptick; and that the Sun obſerved from the *Earth* ſeemed to deſcribe the ſame Circle in the Heavens, that a Spectator in the Sun would ſee the *Earth* really to move in. But the place of the *Earth* ſeen out of the Sun is always diametrically oppoſite to that point of the Ecliptick in which we on the *Earth* obſerve the Sun to be placed: And therefore when the Sun appears to us in ♈, the *Earth* is really in ♎; when he is in ♋, the *Earth* has its Manſion in ♑. And therefore from the apparent place of the Sun, which we find out by Obſervation, we can eaſily determine the place of the Earth in its proper Orbit.

The Sun is twice every Year in the Equinoctial Circle.

SINCE the Ecliptick cuts the Equator in two oppoſite Points, the Sun will twice every Year appear in the Equator or Equinoctial Circle, which happens when by his apparent Motion he arrives at the Interſections of theſe two Circles: All the reſt of the Year he will ſeem to decline either to the North or South from the Equator; and he is at his fartheſt diſtance from the Equator when he is juſt in the middle between the two Sections, that is, 90 Degrees removed from either, and there the Sun does not ſeem to alter his Declination for ſome time; and then the Days keep the ſame length: And therefore theſe points which are the firſt of ♋ and ♑ are called the *Solſtitial Points*, as the Interſection of the Equator and Ecliptick are called the *Equinoctial Points*, becauſe when the Sun is ſeen in them the Days and Nights are equal.

SINCE the Sun is ſeen continually moving in the Ecliptick, and every Day ſeems to advance a Degree Eaſtward, he makes no ſtay in the Equinoctial Points; but in paſſing on, in the ſame Moment he arrives there he leaves them: And therefore tho' the Day the Sun enters the Equinoctial point is called the *Equinox*, becauſe it is reputed equal to the Night; yet it is not preciſely ſo, unleſs the Sun enters the Equator at Mid-Day. For if the riſing Sun ſhould enter the Vernal Equinox, at ſetting he will have departed from it, and decline Northwards about the ſpace of 12′; and therefore that Day will be ſomewhat longer than 12 Hours, and the Night ſhorter; but the Difference is ſo ſmall that it may be neglected in this matter.

The Inveſtigation of the Sun's entring the Equator.

THE moment of Time in which the Sun enters the Equator is found out by Obſervation, and from the Latitude of the place of the Obſerver. For in the Equinoctial Day or near it, with an Inſtrument exactly divided into Degrees, Minutes and parts of Minutes, take the Meridian Altitude of the Sun: If it be equal to the Altitude of the Equator, or to the Complement of the Latitude, the Sun is in that very Moment in the Equator; but if it is not equal take the Difference and mark it, for it will be the Declination of the Sun. Then the next Day again obſerve the Meridian Altitude of the Sun, and gather from thence his Declination. If theſe two Declinations be of different kinds, as the one South and the other North, the Equinox happens ſome time between the two Obſervations, or if they be both of the ſame ſort, the Sun has either not entered the Equinoctial, or has paſt it. And from theſe two Obſervations of the Sun's Declination the Moment of the Equinox is thus inveſtigated.

Table XXII. Fig. 1.

LET CAB be a portion of the Ecliptick, ÆAQ an Arch of the Equator, and let their Interſection be in A. Let CÆ be the Declination of the Sun at the time of the firſt Obſervation, ED his Declination in the ſecond Obſervation, the Arch C E will be the Motion of the Sun in the Ecliptick for one Day. In the ſpherical Triangle A Æ C Right-angled at Æ, we have the Angle A which the Equator and the Ecliptick make, which we ſhewed how to find out in *Lecture* XIX; as alſo C Æ the Declination of the Sun known by Obſervation, by which we ſhall find the Arch C A. And in the ſame manner in the Triangle A E D the ſide A E is found, and thence the Arch C E, which is the Sum or Difference of the Arches C A, A E. Say then as C E is to C A, ſo is 24 Hours to the time between the firſt Obſervation and the Moment of the Ingreſs of the Sun to the Equinox.

The quantity of the Tropical Year.

IF again the next Year the time of the Sun's Entry in the Equator be obſerved in the ſame manner, the Time elapſed between the two Ingreſſes is the ſpace of a *Tropical Year*, or the Time wherein the Sun or rather the *Earth* compleats its Courſe in the Ecliptick; which is called the *Tropical Year*, becauſe after it is finiſhed, all the Seaſons return again in the ſame Order. But by Obſervations that are made at the diſtance of a Year, we cannot ſafely rely upon the true quantity of the Year collected from them; for a ſmall Error of one Minute being conſtantly encreaſed and multiplied by the Number of Years, in proceſs of Time would amount to a prodigious miſtake in the place of the Sun. Therefore the *Aſtronomers* more accurately determine the quantity of the Year, by taking the Obſervations of two Equinocties at many Years diſtance from one another, and dividing the Time between the Obſervations by the number of Revolutions the Sun has made; the Quotient will ſhew the time of one Revolution, or nearly the Period of the *Earth* in her Orbit. For by this means, if there be any miſtake made in the Obſervation, it will be divided into ſo many parts, according to the number of Years, that it will be inſenſible for the ſpace of one Year.

The Anomaliſtical Year.

THE ſpace of Time belonging to the *Tropical Year* is by this means found to conſiſt of 365 Days, 5 Hours, 48 Minutes and 57 Seconds. This Time is ſomewhat leſs than the Periodical Time of the *Earth* in her Orbit, which is called the *Anomaliſtical* or *Periodical Year.* For by reaſon of the Præceſſion of the Equinoctics, which was explained by us in the VIII*th Lecture*, by which the Points of Interſection do conſtantly every Year move back 50 Seconds, and as it were meet the Sun; the Sun will arrive at the Interſection before he has compleated his Courſe. Now the Time of the *Earth*'s Period or *Anomaliſtical Year* is 365 Days, 6 Hours, 9 Minutes and 14 Seconds.

The Motion of the Sun in the Eclipticks unequal.

IF the Motion of the *Earth* round the Sun were equal, that is, if it deſcribed equal Angles round the Sun in equal times, the apparent Motion of the Sun in the Ecliptick would always be equal, and would proceed each Day in the Ecliptick 59′. 8″.: And therefore the place of the Sun would eaſily be computed for any Time. But we are ſure by Obſervation that the apparent Motion of the Sun is not equal, and that he goes thro' ſome parts of the Ecliptick quicker than thro' others; and particularly in going thro' the Northern Semicircle of the Ecliptick, he ſpends near eight Days more than in paſſing over the Southern Semicircle, which ought to be performed preciſely in the ſame time, if the apparent Motion of the Sun were equal. Moreover, if we make Obſervations, and from them find out the Motion of the Sun in the Ecliptick for each Day; in ſome Days he will be found to move thro' the ſpace of 61 Minutes in a Day; at other times he will ſcarcely be ſeen to have compleated 57 Minutes.

THE daily Motion of the Sun in the Ecliptick is obſerved in this manner. Let C B repreſent the Ecliptick, Æ Q the Equator, whoſe common Interſection is in A: Take with an Inſtrument the Meridian Altitude of the Sun; the Altitude of the Equator in the place of Obſervation is likewiſe to be known: The difference of theſe two Arches is the Declination of the Sun, which will therefore be known. Let G be the place of the Sun in the Ecliptick, and F G his Declination. In the Right-angled Triangle G F A, having the ſide F G and the Angle A, we ſhall find the Arch A G the diſtance of the Sun from the Equinoctial point, or his Longitude and Place in the Ecliptick at the time of the Obſervation. The next Day again obſerve the Meridian Altitude of the Sun, and find from thence his Declination, which ſuppoſe to be M L, from which and the Angle A, by the ſame Method, we ſhall find out the Arch M A; from which ſubſtract the Arch A G, and we ſhall have the Arch G M, which is paſſed thro' by the Sun in one Day. The bigneſs of this Arch is mutable, according to the place the *Earth* has in its Orbit.

The circular Hypotheſis of the Antients by which they explain'd the Appearances.

THE Antient *Aſtronomers*, who allowed no Motions in the Heavens but what were circular and equal, that they might give an account of this apparent Inequality of the Sun's Motion, imagined that the Sun moved round the *Earth* or the *Earth* round the Sun (for it is the ſame thing which we ſuppoſe to move or ſtand ſtill) in a circular Orbit, but Eccentrical; that is, whoſe Center was at ſome diſtance from the Center of the Ecliptick, in which they placed either the Sun or the *Earth*; and this circular Orbit they ſuppoſed was deſcrib'd by an equal Motion: And therefore becauſe the Center of the Ecliptick was at ſome diſtance from the Center of equal Motion, the Motion of either the Sun or *Earth* ſeen from the Center of the Ecliptick would appear unequal.

Table XXII, Fig. 2.

LET the Circle ♈ ♋ ♎ ♑ repreſent the Ecliptick, in whoſe Center is the Sun, M P N A the Orbit of the *Earth* whoſe Center is C, diſtant from the Center of the Ecliptick by the Line C S, which is called the Eccentricity. They ſuppoſed the *Earth* to move in this Circle with an equal

Motion: And therefore all the Angles deſcribed round the point C would be proportional to the Times, and the *Earth* ſeen from C would not appear to move ſlower in A than in P; but viewed from the Center of the Ecliptick, becauſe at A it is farther diſtant than in P, it would appear to deſcribe leſs Arches in equal times: And therefore when the *Earth* is in A, and a Spectator in it, obſerving the Sun in ♋, will find that he moves ſlower than when the *Earth* is in P, and the Sun is ſeen in ♑. And becauſe the Arch of the Circle MAN is greater than a Semicircle, and NPM leſs than one; it is evident that there is more Time required to deſcribe the Arch NAM than NPM: But in the time the *Earth* is carried thro' the Periphery NAM, the Sun ſeems to deſcribe the Northern Semicircle of the Ecliptick, *viz.* ♈, ♋, ♎: And while the *Earth* is moving thro' the Arch MPN, the Sun will ſeem to have gone thro' the other, or the Southern Semicircle ♎, ♑, ♈. From hence the reaſon is plain why the Sun ſtays longer in the Northern Signs than he does in the Southern.

The Determinations of the Eccentricity and Poſition of the Apſides *on this Suppoſition.*

UPON theſe Suppoſitions they thus determined the Eccentricity and Poſition of the *Apſis.* In the ſame Year obſerve the Moments of Time wherein the Sun enters both the Equinoctial Points, *viz.* the Vernal and Autumnal, as alſo the place of the Sun in the Ecliptick in any other intermediate Time; which ſuppoſe to be in ♌, the *Earth* being really in ♒. When the *Earth* is in the point of its Orbit N, the Sun is ſeen in the point ♈; then the *Earth* coming to L, the Sun appears in ♌; and when it has arrived in M the Sun will be obſerved in ♎. Draw to the place of the *Earth* in L the right Lines SL, CL. Let likewiſe CM, MN and CN be joined; and let CM and SL cut one another in O. By Obſervations of the Places of the Sun we have the Angle ♈S♌, as likewiſe its Complement to two Right-Angles ♒S♈. Alſo by the diſtance of the Time between the Obſervations we have the Arch L M or the Angle L C M, as alſo the Arch N A M, theſe being proportional to the Times: Therefore we have likewiſe the Arch M P N and the Angle M C N. In the Iſoſceles Triangle M C N, having the Angle M C N, we have likewiſe the two Angles at the Baſe M and N: But in the Triangle M O S we have the Angle M S O and the Angle M: Therefore we have alſo the Angle M O S and L O C which is vertical and equal to it. Suppoſe L C the Radius of the Eccentrick to conſiſt of 100000 equal parts, then in the Triangle L O C, having all the Angles and the ſide L C we can find the ſide O C. But we know M C which is equal to L C: Therefore we have M O. In the Triangle M O S we have all the Angles and one ſide M O, and therefore we ſhall have O S. Laſtly, In the Triangle S O C having S O and O C, and the Angle S O C which is the Complement of the Angle S O M to two Right-Angles, we ſhall find S C the Eccentricity, and the Angle O S C; to which add the Angle M S O, and we ſhall have the Angle M S A or the Arch ♈ ♑; which ſhews the Poſition of the *Aphelion* or its diſtance from the Equinoctial point ♈.

BY this Method the Ancients found the Eccentricity to be 3450 of ſuch parts as the Radius of the Eccentrick was 100000; from which they eaſily calculated the Motion and place of the Sun for any given Time, in the manner following. In the Orbit of the *Earth* let A P be the Line of the *Apſides*, and ſuppoſe the *Earth* at L deſcribing its circular Orbit, the Arch A L or the Angle A C L proportional to the time will be the *Earth*'s mean *Anomaly*, as the Arch of the Ecliptick ♈ ♒, or the Angle ♑ S ♒ is the true Anomaly. Having now the mean Anomaly we have its Sine L Q, and its Co-ſine C Q, to which add the known Eccentricity, and we ſhall have S Q: Say as S Q is to L Q, ſo is the Radius to the Tangent of an Angle, which is Q S L; which therefore will be known. Or thus, In the Triangle S C L we have the ſides S C and C L, and the Angle S C L the Complement of the mean Anomaly to two Right-Angles: Therefore we can find the Angle L S C or L S A the true Anomaly; for as C L + C S : C L — C S : : Tangent of half the Angle L C A to a fourth, which will be the Tangent of half the difference of the Angles C S L and C L S: And becauſe S C and C L are given and conſtant Quantities, the Difference of the Logarithms of C L + C S and C L — C S will be a conſtant Quantity; and if it be always ſubſtracted from the Log. Tangent of half the Angle LCA, we ſhall have the Log. Tangent of half the Difference of the Angles C L S and C S L: But we have their Sum, and conſequently the Angle L S A will be known; which ſhews the place of the *Earth* in the Ecliptick ſeen from the Sun, and the point oppoſite is the place of the Sun ſeen from the *Earth*. In the firſt half Circle of Anomaly A L P, the mean Anomaly A C L is greater than the true Anomaly A S L. For the external Angle A C L is greater than the internal and oppoſite A S L: And if from the mean Anomaly A C L you take away the Angle C L S, there will remain the Angle L S C the true Anomaly. In the ſecond Semicircle of Anomaly, the mean Anomaly is leſs than the true. For ſuppoſe the *Earth* in R, the mean Anomaly is the Arch A P R, or caſting away the Semicircle the Arch P R, or the Angle P C R: But the true Anomaly rejecting the Semicircle is P S R, which is equal to P C R and C R S. Therefore, if to the Mean Anomaly we add the Angle C R S we ſhall have the true Anomaly P S R, and the place of the *Earth* in the Ecliptick. The Angle C L S or C R S is called the *Equation* or *Proſthaphæreſis*, becauſe ſometimes it is to be added, ſometimes to be ſubſtracted from the mean Motion, that we may have the true Motion or place of the *Earth*.

THIS Theory of the Antients anſwered well enough to the apparent Motions of the Sun, which was founded on Obſervations that were not very accurately made. But it was evident from Obſervations of the other Planets, that their Motions could not be accounted for by ſuch a Theory. And even in the Sun itſelf there is a *Phænomenon* which is not to be explained by the Theory of the Antients; but clearly overturns that Theory, and proves it to be falſe, *viz.* By the moſt accurate Obſervations we find that the apparent Diameter of the Sun, when he is in his *Apogæon*, is 31′. 29″; in his *Perigæon* it is 32′. 33″. But the apparent Diameters are reciprocally as the Sun's diſtances. From whence we find that the true diſtance in the *Apogæon* is to the diſtance in the *Perigæon* as 1953 is to 1889, or as 101661 is to 98339; ſo that the Eccentricity is but 1661 of ſuch parts, whereof the Radius of the Eccentrick is 100000: The Theory of the Antients makes the Eccentricity above double of this. And therefore that Theory muſt be falſe which ſuppoſes ſo great an Eccentricity: For if we ſhould allow but one half for the Eccentricity, that would better anſwer to the apparent Diameters of the Sun, when they are nicely obſerved: But then on the other hand, ſo ſmall an Eccentricity would not account for the Inequalities of the Sun's Motion, making the Center of the Eccentrick the Center of the middle Motion: For by computing, we find the *Equations* or *Proſthaphæreſes* twice as great as what they would amount to with half only of the Eccentricity of the Antients. And therefore it is plain that this Theory of the Antients muſt be falſe.

The Theory of the Antients is not true.

THE ſagacious *Kepler* obſerving this, ſhewed that the Eccentricity was indeed to be biſected; but ſo, that the Center of the Eccentrick was in D, in the middle point between the Sun and the point C; from which C, if the Motion of the *Earth* were viewed, it would appear equal. This point C, which was diſtant from the Center of the Eccentrick by half the Eccentricity of the Antients, was called the Center of the middle Motion, becauſe from it the Motion of the *Earth*

Kepler's *Correction of it.*

would always be ſeen in a mean Motion, between its quick and ſlow progreſs in the Ecliptick.

'TIS true, *Copernicus* and many other *Aſtronomers* thought it abſurd to ſuppoſe the *Earth* carried in a Circle whoſe Center was not the Center of the equal Motion; for then the *Earth*'s Motion muſt not only be in Appearance, but really in it ſelf unequal; and in ſome parts of the Periphery of its Orbit it would move faſter, in other ſlower, contrary to their eſtabliſh'd Maxim of having all the Motions perfectly uniform.

Kepler's *Elliptick Theory.*

BUT *Kepler*, when he had demonſtrated that *Mars* and the other Planets were not carried round the Sun in circular, but in Elliptical Orbits; and that the Sun was in one of the *Foci* of thoſe Ellipſes; and that the Planets in moving round him did ſo regulate their Motions, that a Line or Ray drawn from the Sun to the Planet did ſweep an *Elliptick Area* or ſpace always proportional to the Time the Planet moved. He thought it but reaſonable to ſuppoſe the *Earth* in turning round the Sun ſhould obſerve the ſame Law, and be carried likewiſe in an Elliptick Orbit. This Theory anſwers exactly to all Appearances; but it follows from it that there are no Centers of equal or middle Motion from which the Planets can be ſeen to deſcribe Angles proportional to the Times. And therefore many *Aſtronomers* ſtill adhering to the Opinion that there were Centers of equal Motion, rejected this Theory of *Kepler*'s; but for all that they retained the Elliptick Form of the Planetary Orbits. And becauſe in the Axis of an Ellipſe there are two points equally diſtant from the Center, which are called the *Foci*, in one of which they, with *Kepler*, placed the Sun; the other, which was diſtant from the Sun the double of the Eccentricity, they imagined to be the Center of equal Motion, and round it they ſuppos'd the Planets to deſcribe Angles proportional to the Times; which indeed in Ellipſes, that are not very Eccentrical, is nearly true, as *Kepler* himſelf acknowledges,

There are no Centers of middle Motion.

and we ſhall hereafter demonſtrate. This Hypotheſis they liked the better, becauſe there was no direct or Geometrical Method in the Theory of *Kepler*, to find out the true Anomaly from the Mean, which by the other Theory they could eaſily find. Upon the account of this deficiency of Method, many *Aſtronomers* objected to *Kepler* ἀγεωμετρησίαν, or want of *Geometry* in his Theory; and rejecting it, went upon other Hypotheſis which did not ſo well agree with the true Laws of Nature; and they feigned, that in each Orbit there was a certain point for the Center of equal Motion, round which the Planets deſcribed Angles proportional to the Times: But ſince the Theory of *Kepler* is that which does really obtain, and only has place in Nature; and all Obſervations declare that the Planets do really regulate their Motions by its Laws; it is not to be rejected upon the account of a want in *Geometry*, nor is the fault to be layed upon the Theory, which is rather to be imputed to the unskilfulneſs of the *Aſtronomers* in *Geometry*. We therefore, that we may remove this blemiſh of want of *Geometry* for the future, in the following *Lecture* will ſhew a direct Method of finding the true Anomaly of a Planet from its mean Anomaly given.

Kepler's *Theory eſteemed ungeometrical.*

LECTURE XXIII.

Of the Motion of a Planet in an Ellipſe, And the Solution of Kepler's *Problem about the cutting of the* Elliptick Area.

THE Great *Kepler* was the firſt who demonſtrated that the Planets did not move in circular Orbits, but that they were carried round the Sun in Elliptical ones, all which had one common *Focus*, in which the Sun reſided: And that the Planets in their Motions conſtantly obſerved a certain Law, *viz.* that a Ray or Line reaching from the Sun to the Planet did ſweep Elliptical Spaces that were proportional to the Times.

By Kepler's *Theory Sir* Iſaac Newton *found out the Phyſical Cauſes of the Planets Motions.*

THIS admirable and Divine Invention of the ſagacious *Kepler* was owing to the exact Obſervations of *Tycho Brahe*; and is ſo much more to be valued, for that by the help of it, the moſt incomparable *Philoſopher* Sir *Iſaac Newton* diſcovered the Univerſal Laws of Motion, the Syſtem of the Univerſe, and the whole Body of the Celeſtial *Philoſophy*, which was intirely unknown before. *Kepler* alſo demonſtrated, from Obſervations of the Motions, that in all the Planets their periodical Times were in a ſeſquiplicate proportion of their mean diſtances from the Sun, or of the greater Axes of the Ellipſes, which are equal to twice the mean diſtances; that is, the Squares of the periodical Times are conſtantly as the Cubes of the greater Axes: And therefore if in two dif-

The proportion of the Planets periodical Times to their Diſtances found out by Kepler.

ferent Ellipſes the greater Axes be called A, a, their periodical Times T and t; then we ſhall have the Analogy $T^2 : t^2 :: A^3 : a^3$, and $T : t :: A^{\frac{3}{2}} : a^{\frac{3}{2}}$.

HENCE it follows that in different Ellipſes, the Area's deſcribed by two Planets in the ſame Time, are in ſubduplicate Proportion of the Parameters or *Latera recta* of the Ellipſes, which I thus prove. It is known from the Property of the Ellipſe that its Area is as the Rectangle under the two Axes of it; that is, if the two Axes of the greater Ellipſe be called A and M, and the two Axes of the ſmaller Ellipſe be called a and m; the Area of the greater Ellipſe will be to the Area of the leſſer as $A \times M$ is to $a \times m$. And therefore when we are ſpeaking of the Proportion of the Area's, we may put theſe Rectangles inſtead of the Area's. In the greater Ellipſe call the Area deſcribed in a given Time X, the Area deſcribed in the leſſer Ellipſe in the ſame time x, and the Time given in which they are deſcribed y; the *Latera recta* of the Ellipſes call L and l, the periodical Times T and t. From the Theory above explained it follows that $X : A \times M :: y : T$, alſo that $a \times m : x :: t : y$. And therefore by Equality of proportion, 'twill be $X \times a \times m : x \times A \times M :: t : T :: a^{\frac{3}{2}} : A^{\frac{3}{2}}$ But ſince the leſſer Axis is a mean proportional between the greater Axis and the *Latus rectum*, M will be $= A^{\frac{1}{2}} \times L^{\frac{1}{2}}$, and $m = a^{\frac{1}{2}} \cdot l^{\frac{1}{2}}$: And therefore $X \times a^{\frac{3}{2}} l^{\frac{1}{2}} : x \times A^{\frac{3}{2}} L^{\frac{1}{2}} :: a^{\frac{3}{2}} : A^{\frac{3}{2}}$: And therefore $X \times l^{\frac{1}{2}} : x \times L^{\frac{1}{2}} :: 1 : 1$; that is in proportion of Equality: And therefore $X : x :: L^{\frac{1}{2}} : l^{\frac{1}{2}}$. And therefore in different Ellipſes, the Area's deſcribed in the ſame time are as the ſquare Roots of their *Latera recta*.

The Area's deſcribed in the ſame Time proportional to the Latera recta of the Ellipſes.

SINCE therefore the Law by which the Planets regulate their Motions is the equal or uniform Deſcription of the Area's, it is impoſſible that the Planets can every where move with the ſame uniform Velocity, but it muſt conſtantly be changed: So that going from the *Perihelion* to the *Aphelion* they muſt conſtantly ſlacken their Pace; but as they deſcend from the *Aphelion* to the *Perihelion* they muſt again quicken their Motions; And in the *Aphelion* they have the ſloweſt, in the *Perihelion* the quickeſt Motion: And the Velocity will be every where reciprocally as a Perpendicular that falls upon a Right Line paſſing thro' the Planet and touching the Orbit. Let D A F be an Ellipſe, whoſe *Focus* is S; and ſuppoſe the Arches A B, *a b* thereof to be gone over by the Planet in equal times that are exceeding ſmall, the Triangles S A B and S *a b* will be equal, for they are the Area's that the carrying Ray deſcribes in equal times. From the *Focus* S let fall on the Tangents the Perpendiculars S P, S *p*, and the Triangle SAB will be equal to $\frac{1}{2}SP \times AB$: So likewiſe the Triangle S *a b* will be equal to $\frac{1}{2}Sp \times ab$: And therefore $SP : Sp :: ab : AB$: But A B and *a b*, ſince they are Lines deſcribed in the ſame Time, are as the Velocities: Wherefore the Velocity in A is to the Velocity in *a* as S *p* is to S P the Perpendicular. Mr. *De Moivre*, in the *Philoſophical Tranſactions* N°. 352, has likewiſe demonſtrated the two following *Theorems* concerning the Elliptick Motion.

The Velocity every where reciprocal to the Squares of their diſtances.

Plate XXII. Fig. 3.

THEOREM I.

A Theo*rem to determine the proportion of the Velocity.*

Table XVI. Fig. 7.

LET A P B be the Elliptick Orbit, in which ſuppoſe a Planet to move round the Sun in the Focus *S. Let C be the Center of the Ellipſe, C B half the greater Axis, C D half the leſſer, and F the other* Focus. *The Planet being in P, draw the Right Lines S P, F P; then the Velocity of the Planet in P, will be to the Velocity in its mean diſtance S D, in a ſubduplicate proportion of its diſtance F P from the* Focus *F, to its diſtance S P from the* Focus *S.*

Let the Right Line E P G touch the Ellipſe in P, and from each of the *Foci* on the Tangent let fall the Perpendiculars SE, FG; and let SH be a Perpendicular on the Tangent DH. The Velocity in P is, as we have ſhewed, to the Velocity in D, as SH is to SE: And therefore the Square of the Velocity in P is to the Square of the Velocity in D, as SH Square or CD Square to SE Square; that is, by the Nature of the Ellipſe (becauſe CD Square is equal to SE × FG) as SE × FG is to SE Square, or as FG to SE. But becauſe of the equiangular Triangles FG is to SE as FP is to SP: Wherefore the Square of the Velocity in P is to the Square of the Velocity in D as FD is to SP: And conſequently the Velocity in P is to the Velocity in D as $\sqrt{FP}$ is to $\sqrt{SP}$, which was to be demonſtrated.

THEOREM II.

THE Radius is to the Sine of the Angle SPE as $\sqrt{SP \times FP}$ to CD. For SP Square is to $SP \times FP :: SP : FP :: SE : FG ::$ SE ſquare : $SE \times FG ::$ SE ſquare : CD ſquare. And by Alternation of Proportion SP ſquare : SE ſquare :: $SP \times FP$: CD ſquare: And therefore $SP : SE :: \sqrt{SP \times FP} : CD$: But $SP : SE ::$ Radius is to the Sine of the Angle SPE. Therefore as the Radius is to the Sine of the Angle SPE, ſo is $\sqrt{SP \times FP}$ to CD, which was to be demonſtrated.

The angular Velocity at the Sun is as the Square of their diſtances reciprocally.

Plate XXII. Fig. 3.

WE have already ſhewed the Proportion by which the abſolute Velocity increaſes or decreaſes: But we have another *Theorem* for determining the angular Velocity, or the Angle which a Planet ſeen from the Sun will appear to deſcribe in a ſmall Particle of Time: For it is every where reciprocally in a duplicate proportion of the diſtance from the Sun; which I thus demonſtrate. At the Center S, at the diſtances SB, S*b* deſcribe the ſmall Arches BE, *b e*, where AB, *a b* are the ſmall Elliptick Arches deſcribed in equal Times:

In S B take S *m* equal to S *b*, and draw the ſmall Arch *m n*: And the angular Velocity in *b* is to the angular Velocity in B as the Arch *b e* is to the Arch *m n*: But the proportion of *b e* to *m n* is compounded of the proportion of *b e* to B E, and of B E to *m n*. And becauſe the Triangles B S A and *b* S *a* are equal, *b e* will be to B E as S B is to S *b*: And becauſe the Arches B E and *m n* are ſimilar, B E is to *m n* likewiſe as S B to S *m* or as S B to S *b*: Wherefore the proportion of *b e* to *m n* is compounded of the proportion of S B to S *b*, and again of S B to S *b*; that is, the angular Velocity at *b* is to the angular Velocity at B as the ſquare of S B is to the ſquare of S *b*, that is reciprocally as the ſquares of the Diſtances.

The angular Velocity of a Planet compared with an equal Velocity of a body moving in a Circle.

Plate XXII. Fig. 4.

BUT for to explain more clearly the Inequality of the Planets Motions, and the various Increaſe and Decreaſe of their angular Velocities, it will be requiſite to compare their Motions in different points of their Orbit, with an equal and uniform Motion of a body moving in a Circle. Let therefore the Ellipſe A E B F be the Orbit of a Planet in whoſe *Focus* is the Sun S. its greater Axis A B and leſſer O Q. At the Center S and diſtance S E, which is a mean proportional between A K and O K the two ſemiaxes, deſcribe the Circle C E G F. The Area of this Circle will be equal to the Area of the Ellipſe, as it is eaſily to be demonſtrated from the Nature of the Ellipſe: And let us ſuppoſe a point to move with an uniform or equal Motion thro' the Periphery C E G F, in the ſame time that the Planet deſcribes the Ellipſe: And when the Planet is in its *Aphelion* A, let the circulating point be in C, in the Line of the *Apſides*. The Motion of this point will repreſent the equal or middle Motion of the Planet, and the point will deſcribe round S Area's or Sectors of Circles which are proportional to the Times, and equal to the Elliptick Area's the Planet at the ſame time deſcribes. Let now the equal Motion or the Angle round S proportional to the Time be C S M; and take the Area A S P equal to the Sector C S M, and then the place of the Planet in its own Orbit will be P, and the Angle M S D, the difference between the true Motion of the Planet and its mean Motion, is the Equation or *Proſthaphæreſis*: And the Area A C D P will be equal to the Sector D S M, and conſequently proportional to the *Proſthaphæreſis*; And conſequently where this Area is biggeſt, there the *Proſthaphæreſis* or the Equation will be biggeſt: But the Area is biggeſt in the point E, where the Circle and the Ellipſe cut each other. For when the Planet deſcends further to R, the Equation becomes proportional to the difference of the Area's A C E and *m* E R, or to the Area G B R *m*. For when the Planet is in R, let V be the place of the point moving uniformly in the Circle, the Sector C S V will be equal to the Elliptick Area A S R: And taking away the common ſpaces, the Area A C E leſs the Area R E *m* is equal to the Sector V S *m* or to the Equation.

The Area proportional to the Proſthaphæreſis.

Where the Equation is greateſt.

IN the *Perihelion* the equal Motion and the true Motion of the Planet coincide; for the Semicircle C E G is equal to the Semiellipſe A E B. But after the Planet departs from the *Perihelion* B, its Motion is conſtantly quicker, and it goes before the point moving equally with the mean Motion. For let the Angle G S Z be proportional to the Time, take the Area B S Y equal to the Sector G S Z, and Y will be the place of the Planet in its Orbit; and the Angle B S Y will be greater than the Angle G S Z; and the Area G B Y L will be equal to the Sector Z S L, whoſe Angle is the Equation: And where the Area G B Y L is greateſt, there the Equation is greateſt, that is, in the point F, where the Circle and Ellipſe cut one another. In A the Velocity of the Planet is the leaſt of all, becauſe the diſtance S A is the greateſt; from thence the Planet deſcending to its *Perihelion*, its Velocity will conſtantly encreaſe; but it will ſtill be leſs than the mean Velocity, till it comes to E, the Interſection of the

Ellipſe and Circle: And there its Velocity becomes juſt equal to the mean; which I thus prove. When the Planet is in E, let the point going with the equal or mean Velocity be in m, and the Area's deſcribed round S in the ſame infinitely ſmall Time be nSE and the Sector iSm, which will be equal. And therefore $hE \times ES$ is equal to $im \times ms$: And therefore becauſe Sm and SE are equal, hE and im muſt be equal; and the Angle nSE will be equal to the Angle iSm. At the point therefore E the angular Velocity of the Planet is equal to its mean Velocity: The Planet going from E, and approaching ſtill nearer to its *Perihelion*, the Velocity grows bigger than the mean Velocity, and its diſtance from the Sun being conſtantly decreaſing, the Velocity will continually increaſe, till it comes to the *Perihelion*, where it is the greateſt of all, becauſe the diſtance S B is the leaſt of all. The Planet departing from thence, and aſcending to the *Aphelion*, it leaves the point which proceeds conſtantly with the middle Motion, behind it; but as it goes farther off from the Sun its Velocity decreaſes, but is ſtill bigger than the mean Velocity, till it comes to F, the point of Interſection of the Ellipſe and the Circle, where the Planet's angular Velocity is again equal to the mean angular Velocity; and when it has paſſed that point its Velocity becomes leſs than the mean, and conſtantly diminiſhes till it arrives at the *Aphelion*, where it is the leaſt of all; its diſtance from the Sun being then greateſt of all.

SINCE therefore each Planet in different parts of its Orbit has different Degrees of Velocities, and the only Equality which is obſerved in its Circulation round the Sun is the equal Deſcription or Increaſe of the Elliptick Area, which grows bigger uniformly with the Time; for to determine the place of a Planet in its Orbit at any given Time, we muſt take an Elliptick Area that is proportional to the Time. And to do this it is neceſſary to ſolve the following *Problem*.

KEPLER's PROBLEM.

To find the Poſition of a Right Line, which paſſing thro' one of the Foci *of an Ellipſe, ſhall cut off an Area deſcribed by its Motion, which ſhall be to the whole Area of the Ellipſe in a given Proportion.*

LET the Ellipſe be A P B, whoſe *Focus* is S. I muſt find the Poſition of the Right Line S P, which cuts off the Trilineal Area A S P, to which the whole Area of the Ellipſe has the ſame Proportion that the Periodical Time of the Planet has to any other given Time; which Poſition being found we ſhall have the place the Planet is in at the given point of Time. Or let A Q B be a Semicircle deſcribed on the greateſt Axis of the Ellipſe; we muſt draw from S the Line S Q, which ſhall cut off the Area A S Q, to which the Area of the whole Circle is in the above-mentioned Proportion. For by ſuch a Section of a Circle the Section of the Ellipſe is eaſily found out, by letting fall from the point Q a Perpendicular on the Axis A B; which will cut the Ellipſe in the point P required, to which draw the Line S P, and it will be the Right Line which divides the Area of the Ellipſe in the given Proportion; ſo that P will be the place of the Planet. For the Elliptick Segment A P H is to the circular Segment A Q H as H P is to H Q; that is, as the Area of the whole Ellipſe is to the Area of the whole Circle, as is known from the nature of the Ellipſe: But the Triangle S P H is to the Triangle S Q H in the very ſame proportion by *Prop.* 1. *El.* VI. And therefore by *Prop.* 12. *El.* V. the Elliptick Area A S P is to the circular Area A S Q, as the Area of

Table XXII. Fig. 5.

of the whole Ellipſe is to the whole Circle: And by Alternation the Area A S P is to the whole Ellipſis as the Area A S Q is to the Circle. Hence if we have a Method of drawing thro' S a Line which will cut the Area of the Circle in a given proportion, it will be eaſy to cut the Area of the Ellipſe in the ſame proportion.

The Anomaly of the Eccentrick.

KEPLER, who firſt propoſed the *Problem*, knew no direct Method of computing the Planet's place from the Time; and expreſly tells us; that there was no direct way of finding, from the Time given, the true Anomaly of the Planet; or its place in its Orbit. And therefore he found it neceſſary to go thro' every Degree of the Semicircle A Q B; and to ſearch from the Arch A Q, which he called the *Anomaly of the Eccentrick*, the Time which was expreſſed by the Area A S Q, which is proportional to the mean Anomaly; as alſo the Angle A S P, which gives the true Place and true Anomaly of the Planet, which he computed by Calculation. And therefore becauſe he could not directly and Geometrically ſolve the *Problem*, ſome *Aſtronomers* objected to him an *ἀγεωμετρησία* or want of *Geometry*; and that he was ſo fond of Phyſical Cauſes, that he had departed from *Geometry*; and they blamed his *Aſtronomy* as not being Geometrical, ſince it was founded on ſuch a Theory. And therefore that they might eſcape the committing of ſuch a fault, they went upon other *Hypotheſes*, and feigned a point round which the Planets Motion ſhould be equal, or the Angles proportional to the Times: And from thence, the mean Anomaly being given, they calculated the true place of the Planet. But the Calculations founded on theſe *Hypotheſes* was found not to anſwer Obſervations: For there is really no fixed Point which is the Center of equal Motion, round which the Planets deſcribe Angles proportional to the Times: And the only Theory that anſwers all Obſervations is that above explained of *Kepler*. And therefore the *Aſtronomers* muſt now for ever embrace this Theory of *Kepler*, ſince it not only agrees perfectly with the Motions of the Heavens; but alſo lays moſt elegantly open the Cauſe and Source of all thoſe Motions. *Kepler* himſelf valued this Theory ſo much, that he choſe rather to take up with an indirect Method of Calculation, than contrive another *Hypotheſis* that was not agreeable to the Nature of Things; and for this the ableſt Judges were not diſpleaſed with him. Therefore to take away this blemiſh of want of *Geometry* out of our *Aſtronomy*, we will here ſhew a direct Method by which the Area of an Ellipſe, or of a Circle which is equivalent, may be cut in a given Proportion.

Table XXII. Fig. 6.

LET AQB be a Semicircle whoſe Diameter is the greater Axis of the Ellipſe, its Center C, and S the *Focus* of the Ellipſe in which the Sun is placed. Thro' the place of the Planet imagine a Perpendicular QH to be drawn to the Axis, meeting with the Circle in Q: Then the Area ASQ will be to the whole Circle as the given Time is to the Periodical Time of the Planet. Draw CQ, and from S let fall upon it, produced if required, the Perpendicular SF: The Area ASQ is equal to the Sector ACQ and the Triangle QSC; that is, equal $\frac{1}{2}QC \times AQ + \frac{1}{2}QC \times SF$. And therefore becauſe $\frac{1}{2}QC$ is a conſtant Quantity, the Area ASQ will be always proportional to the Arch AQ + the Right Line SF, when the Motion is from the *Aphelion* to the *Perihelion*: But when the Planet aſcends from the *Perihelion* to the *Aphelion*, the Area BSq is equal to the Sector BCq — Triangle CSq: And therefore it will be proportional to the Arch Bq — the Right Line Sf. Hence if we take the Arch AN or Bn proportional to the Time, $AQ + SF$ will be equal to AN, or $Bq - Sf = Bn$; for then AN and Bn will be proportional to the Area's ASQ and BSq.

HENCE if we have the Arch AQ, and add to it the Arch QN, which is equal to the Right Line SF; the Arch AN will be proportional to the Time, or equal to the mean Anomaly of the Planet: And therefore if we have the true Anomaly of a Planet, we may eaſily find the mean, or the Time. For let Q C be to S C as 57,29578 (which Number expreſſes the length of an Arch in Degrees and parts of a Degree that is equal to the Radius) to a fourth Number: And we ſhall have an Arch equal to S C in Degrees and decimal Parts. Call this Arch B: And becauſe S C is to S F, as the Radius is to the Sine of the Angle S C F or A C Q, ſay as the Radius is to the Sine of A C Q, ſo is the Arch B to a fourth; and then we ſhall have, in Degrees and decimal Parts, an Arch in the Periphery A Q B, which is equal to the Right Line S F: And becauſe S F is equal to Q N, we have the Arch Q N, and alſo the Arch A N, which is proportional to the Time.

LET us explain this by Examples in the Orbit of *Mars.* The Eccentricity of this Orbit is to its mean diſtance as 14100 is to 152369. And therefore the Logarithm of the Arch B, which is equal to S C is 0,7244446: And therefore if we would have the mean Anomaly when the Anomaly of the Eccentrick is one Degree, add the Log. Sine of 1 Degree to the Log. of B, the Sum is 8,9662999: This being the Log. of the Number 0,092533, expreſſes the length of the Arch Q N in decimal parts of a Degree. And therefore the Arch A N or the mean Anomaly is 1,092533 or 1°. 5′. 33″. In like manner, if the Anomaly of the Eccentrick be 30°, to its Log. Sine add the conſtant Log. of B; and the Sum will be 0,4234146; which is the Log. of the Number 2,651. And therefore the mean Anomaly A N anſwering to 30 Degrees of the Eccentrick Anomaly, is 32,651, or 32°.39′.3″. This Method is much quicker and eaſier than that which *Kepler* gives, where, by an indirect Method and the Rule of falſe Poſition, he ſhews how to compute the true Anomaly from the mean.

LET us now come to the Method I promiſed of directly finding the true Anomaly from the

Lecture XXII.

mean. In the Figure let the Arch A N be the mean Anomaly, or proportional to the Time; A Q the Anomaly of the Eccentrick which is to be found. Call the Arch N Q y, and the Sine of A N call e, and Co-ſine f; and let the Eccentricity S C be g. The Sine of the Arch A Q is equal to the Sine of the Arch A N — N Q, equal to the Sine of the Arch A N — y. But we have demonſtrated in the Elements of *Trigonometry*, that if the Sine of the Arch A N be e, the Sine of the Arch AN $- y$, or of A Q, will be $e - \frac{fy}{1} - \frac{ey^2}{1.2} + \frac{fy^3}{1.2.3} + \frac{ey^4}{1.2.3.4}$ &c. But the Radius which is 1 is to the Sine of the Arch A Q as S C or g is to S F or N Q; that is to y: And therefore $y = ge - \frac{gfy}{1} - \frac{gey^2}{1.2} + \frac{gfy^3}{1.2.3} + \frac{gey^4}{1.2.3.4}$ &c. And therefore we have $ge = y + \frac{gfy}{1} + \frac{gey^2}{1.2} - \frac{gfy^3}{1.2.3} - \frac{gey^4}{1.2.3.4}$ &c. Let $ge = z$, and $1 + fg$ call a, $\frac{ge}{2} = b$, $\frac{gf}{1.2.3} = c$; and $\frac{ge}{1.2.3.4} = d$. And the Equation will be in this Form $z = ay + by^2 - cy^3 + dy^4$ &c. And therefore by the Method of Reverſion of Series invented by Sir ISAAC NEWTON, we have $y = \frac{z}{a} - \frac{bz^2}{a^3} + \frac{2b^2 + ac}{a^5} z^3 - \frac{5abc - 5b^3 + a^2 d}{a^7} \times z^4$ &c. But becauſe $b = \frac{ge}{2} = \frac{z}{2}$ and $d = \frac{z}{24}$, we ſhall have $y = \frac{z}{a} - \frac{z^3}{2a^3} + \frac{cz^3}{a^4} - \frac{5cz^5}{2a^6}$ &c. But if the Arch AN be greater than 90 Degrees and leſs than 270, then ge or

$z = y - gfy + \frac{gey^2}{2} + \frac{gfy^3}{1.2.3} - \frac{gey^4}{1.2.3.4}$. And then $a = 1 - gf$, and $y = \frac{z}{a} - \frac{z^3}{2a^3} - \frac{cz^3}{a^4}$ &c. This Series expreſſes the Arch QN in parts whereof the Radius is 100000: But to have it in Degrees and parts of a Degree: Say as the Radius is to this Series, ſo is 57,29578, which are the Degrees of an Arch equal to the Radius, to a fourth; conſequently, ſince the Radius is Unity, if we multiply the Series by 57,29578, which number call R, we ſhall have the Arch y in Degrees and decimal parts $= \frac{Rz}{a} - \frac{Rz^3}{2a^3} + \frac{Rcz^3}{a^4}$ &c. The very firſt Term of this Series $\frac{Rz}{a}$ is ſufficient to determine the Anomaly of the Eccentrick in almoſt all the Planets, nearly enough. For in *Mars* the Error ſeldom exceeds the 200*th* part of a Degree: In the *Earth* it is leſs than the 10000*th* part of a Degree. But it will be beſt to ſhew the uſe of this Method by Examples.

IN the Earth's Orbit the Eccentricity is 0,01691, when the mean diſtance CQ is 1. Suppoſe we are to find the Anomaly of the Eccentrick, and the equated Anomaly when the mean Anomaly is 30 Degrees,

The Log. of Eccentricity is —	8,2281436
The Log. Sine of 30° ——	9,6989700
The Log. of R — —	1,7581226
The Log. of Rz ——	9,6852362
The Log. of a ſubſtract —	0,0063137
The Log. of the Arch y ——	9,6789225

To which anſwers the Number 0,47744, or in ſexageſimal Numbers 28′. 38″: The reſt of the Terms don't amount to the 10000*th* part of a Degree, and may therefore be neglected. If therefore from 30 Degrees we deduct 28′. 38″, we ſhall have the Arch AQ 28°. 31′, 22″. In the Trian-

Lecture XXIII.

gle QCS we have the ſides QC, CS and the Angle SCQ: Wherefore we ſhall have the Angle QSC. The Analogy is QC + CS or AS; QC − CS or BS :: Tangent $\frac{CSQ + CQS}{2}$: Tangent of $\frac{CSQ - CQS}{2}$. Therefore if from the Tangent of half the Angle ACQ we ſubſtract a conſtant Log. 0,0146893, we ſhall have the Tangent of an Angle, which added to half the Angle ACQ gives the Angle CSQ or ASQ, which in the preſent Caſe is 29°. 3′. 7″. But for to find the Angle ASP we muſt diminiſh the Tangent of the Angle ASQ, in the Proportion of the bigger Axis of the Ellipſe to its leſſer. Therefore from the Logarithmick Tangent of ASQ take away the conſtant Log. 0,0000622, which is the Log. of the *Ratio* of the greater Axis to the leſs, and we ſhall have the Log. Tangent of the Angle ASP, which Angle is equal to 29°. 2′. 54″. And this is the coequated Anomaly.

Plate XXII. Fig. 5.

IN the Orbit of *Mars* the Eccentricity is 14100 of ſuch parts as the mean diſtance is 152369. And therefore the Log. of the *Ratio* of SC to CQ is 8,9663226 = Log. of g. Let us find the Anomaly of the Eccentrick when the mean Anomaly is 1 Degree,

The Log. of Eccentricity	8,9663226
The Log. Sine of 1 Deg.	8,2418453
The Log. of R	1,7581220
The Log. of Rz	8,9662899
The Log. of a ſubſtract	0,0384299
The Log. of $\frac{Rz}{a}$	8,9278600

Firſt, THE Number anſwering this Log. is 0,08497, and gives the bigneſs of the Arch NQ; and the Error is leſs than the 30000*th* part of a Degree.

Lecture XXIII.

2*dly*, SUPPOSE the mean Anomaly is 45 Degrees, and I am to find the Anomaly of the Eccentrick.

The Log. of Eccentricity —	8,9663226
The Log. Sine of 45° —	9,8494850
The Log. of R — —	1,7581220
The Log. of R z ——	0,5739296
The Log. of a ſubſtract —	0,0275249
The Log. of $\frac{Rz}{a}$ ——	0,5464047

To which anſwers the Number 3,5189, which is more than the Truth by about 150th part of a Degree: And to correct this Error take the ſecond Term of the Series $-\frac{\overline{Ra+2Rc}\times z^3}{2a^4}$, which will be found equal to the Fraction 0,0065, and ſubſtract this from the firſt, there will remain 3,5124, which expreſſes the Arch NQ true to 100000*th* parts of a Degree.

3*dly*, LET us find out the Anomaly of the Eccentrick when the mean Motion is 100 Degrees: In this Caſe $a = 1 - gf = 0,983930$.

The Log. Eccentricity or of g	8,9663226
The Log. Sine of 100° or of 80°	9,9933515
The Log. of R — —	1,7581220
The Log. of R z ——	0,7177961
The Log. of a ſubſtract —	9,9929598
The Log. of $\frac{Rz}{a}$ ——	0,7248363

The Number anſwering to this Log. is 5,3068, which is greater than the Truth by about the 50*th* part of a Degree: And therefore to correct this Error, double the Log. of $\frac{z}{a}$, and to the Product add the Log. of $\frac{Rz}{a}$, and we ſhall have the Log.

of $\frac{Rz^3}{a^3}$, and the Number anſwering to it is 0,04552, whoſe half 0,02276 is equal to $\frac{Rz^3}{2a^3}$: This being ſubſtracted from the former, there will remain 5,2841 for the Arch NQ; which is not the 10000*th* part of a Degree diſtant from the Truth. It's here to be obſerv'd, that though the ſecond Term of the Series be $-\frac{\overline{Ra+2Rc}\times z^3}{2a^4}$, yet the part of it $-\frac{Rz^3}{2a^3}$ is ſufficient to determine AQ truely to the 10000*th* part of a Degree.

HAVING found the Arch AQ or the Angle ACQ, we compute the Angle ASQ by the Reſolution of the Triangle QCS, whoſe ſides QC and CS are given, with the Angle contained between them: And then the Logarithm Tangent of the Angle ASQ is to be diminiſhed, by taking from it the Logarithm of the *Ratio* of the greater Axis to the leſs: And then there will remain the Logarithmick Tangent of the Angle ASP, which is the true or coequated Anomaly.

* * *

LECTURE XXIV.

Sir ISAAC NEWTON's *Solution of* Kepler's *Problem, and* Ward's *Elliptick Hypotheſis explained.*

OUR Method of Solution explained in the preceding *Lecture*, and that of Sir *ISAAC NEWTON*'s delivered by him in his Principles, *pag.* 101, are built upon the ſame Foundation; which is, that the Right Line SF is equal in length to the Arch QN: But the *Newtonian* Method is not unlike to that uſed by the *Analyſts*, when they extract the Roots of affected Equations: And it is ſo much more to be valued, that it not only gives eaſily the Planets Places whoſe Orbits are nearly circular; but almoſt with the ſame Eaſe it may be uſed to determine the Comets places, who have very Eccentrick Orbits. And this may likewſe be performed by our Method, if inſtead of the Arch **A**N we take another **Arch A** more nearly equal to AQ, whoſe Sine is e; and inſtead of making $z = ge$, ſuppoſe $z = ge + A - AN$. And finding the Sine of the Arch $A \pm y$ we ſhall come to an Equation of the ſame Form with the former, where z and y are much leſs, and conſequently the Series will converge much faſter.

I will here explain the *Newtonian* Method, ſince it is of great Uſe and Expedition, for the ſake of thoſe who are willing to calculate Tables upon Principles grounded on the true Laws of Motion, and not upon abſurd Hypotheſes.

Plate XXII

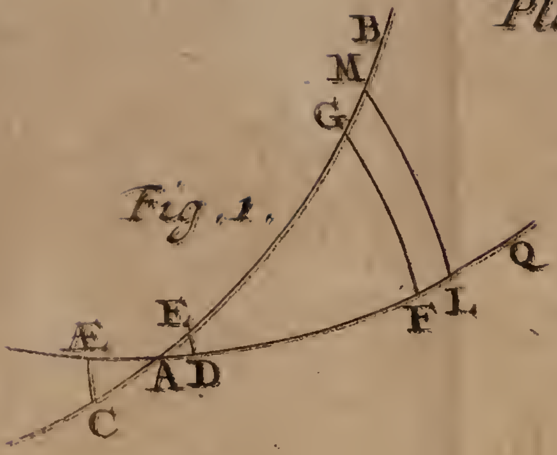


Fig. 1.

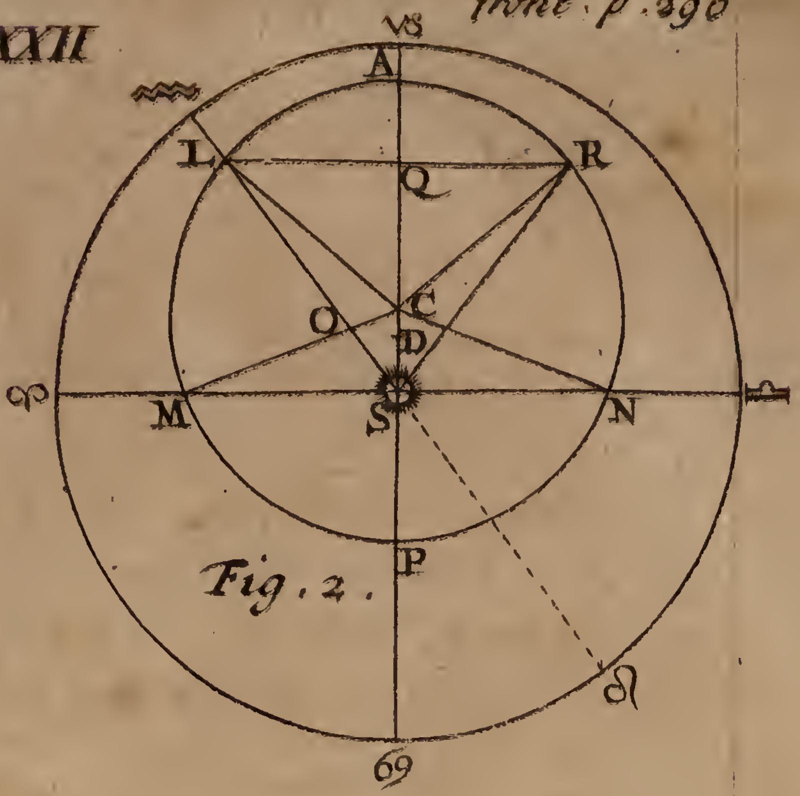


Fig. 2.

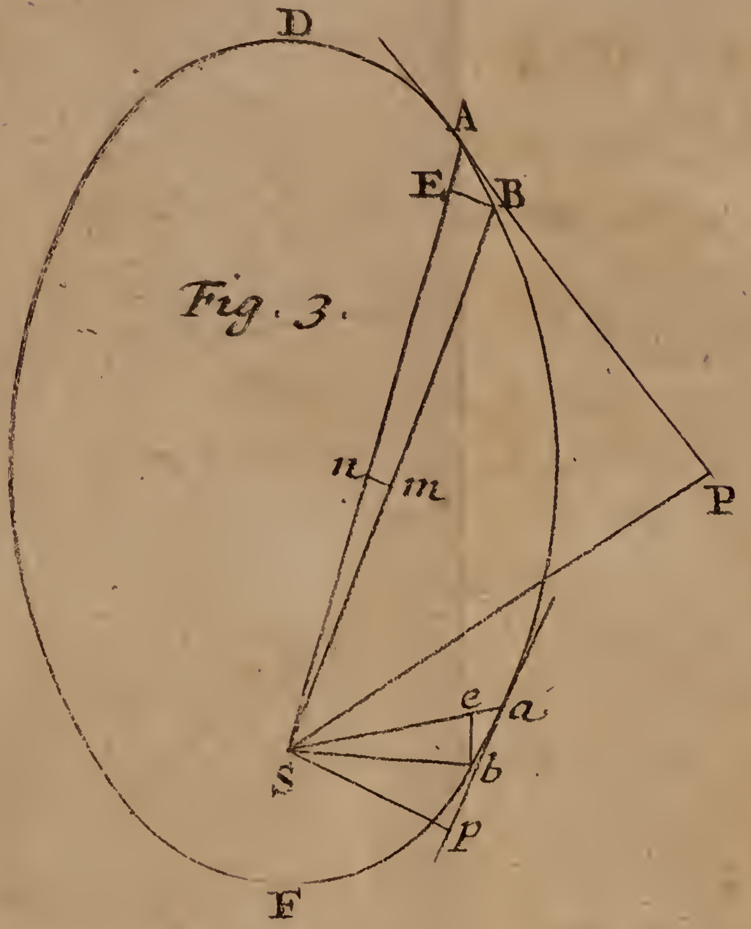


Fig. 3.

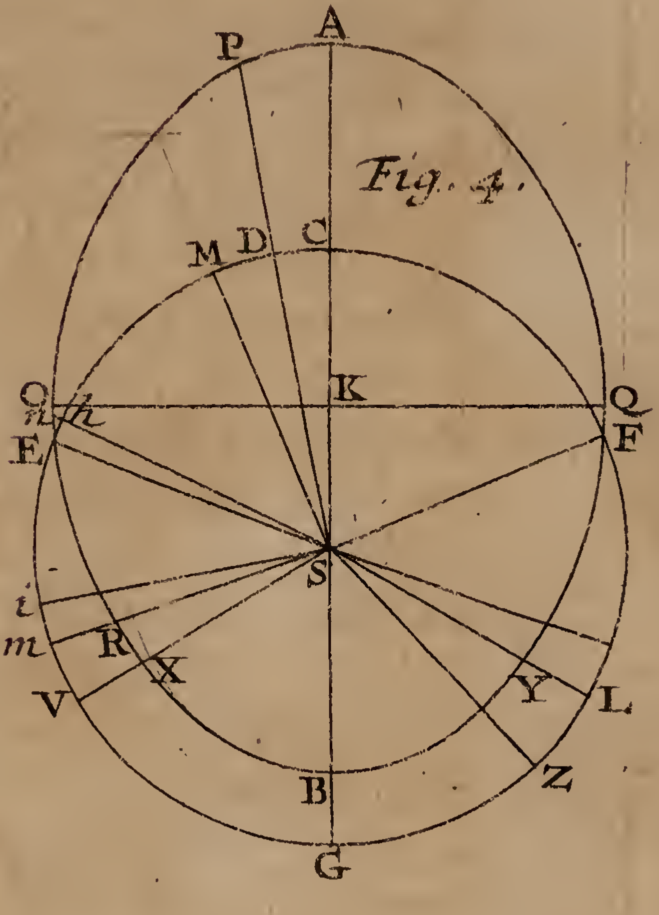


Fig. 4.

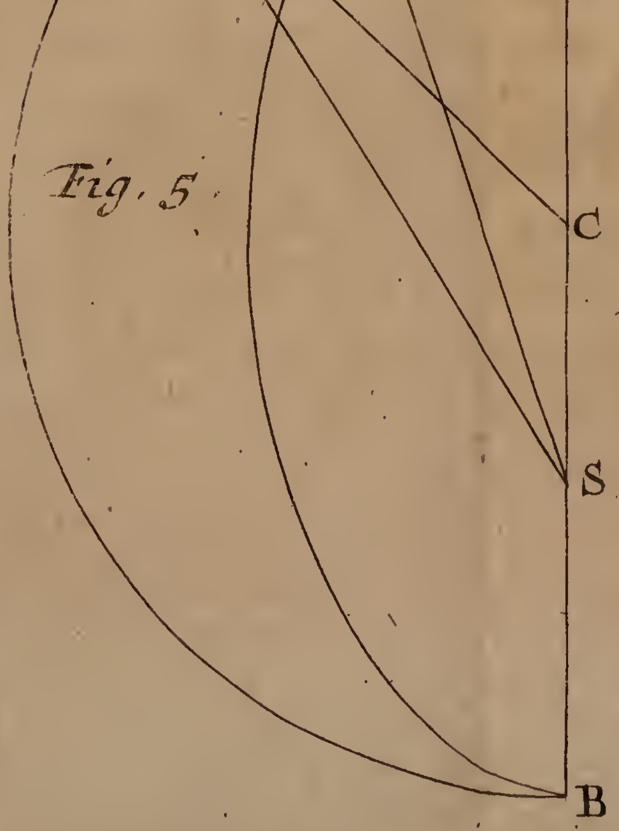


Fig. 5

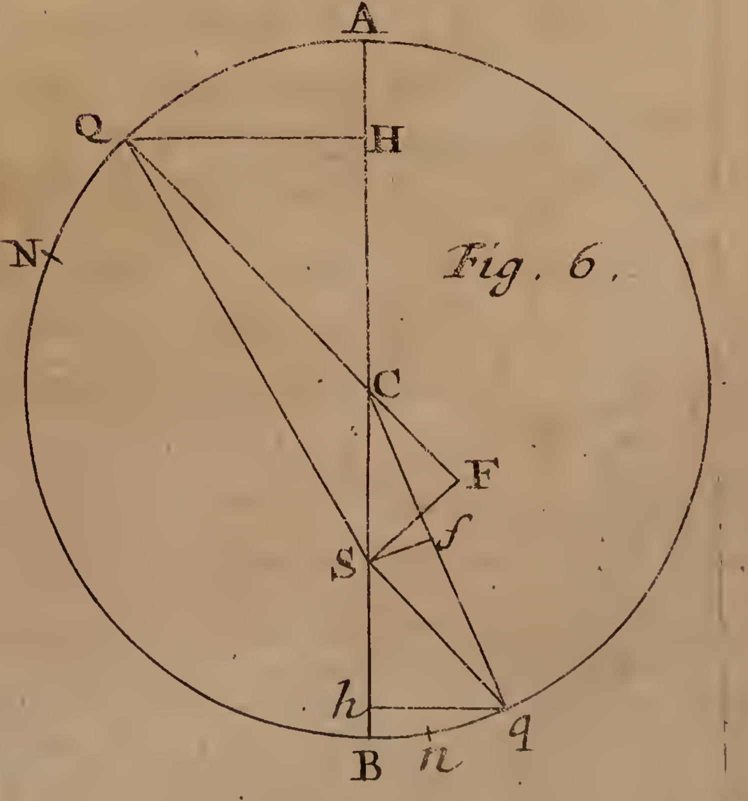


Fig. 6.

Table XXIII Fig. 1.

WE have already ſhewed that if the Arch A Q be the Anomaly of the Eccentrick, that together with the Right Line S F let fall from S upon the Radius C Q perpendicularly, will be proportional to the Time, when the Planet deſcends from the *Aphelion* to the *Perihelion*; and the Difference between the Arch B Q and S F proportional to the time when it aſcends from the *Perihelion* to the *Aphelion*: And therefore if we take the Arch A N or B N proportional to the Time, the Arch Q N will be equal to S F. Therefore to find in Degrees and decimal parts the meaſure of an Arch in the Periphery which is equal to S F: Say as C Q is to C S, ſo is 57,29578 Degrees, which is equal to the Radius, to a fourth: This Number will expreſs the bigneſs of an Arch in the Periphery A Q B which is equal to C S: The Log. of this Arch call B. And becauſe S C is to S F as the Radius is to the Sine of the Angle A C Q; ſay as the Radius is to this Sine, ſo is the Arch whoſe Log. is B to another which call D; then this Arch D will be equal to S F. And therefore if at the given Time the Arch A N and the Area A S Q are proportional each to the Time, and I take N P equal to D, the point P will fall on Q: But if the Area A S Q be not exactly proportional to the Time, the point P will either fall above or below Q, according as the Area A S Q is bigger or leſs than the Truth. Let the true Area be ASq, and upon Cq let fall the Perpendicular S E; which by what we have already ſhewed is equal to Nq: And therefore $SE - SF$ or $SF - SE$, that is nearly the Line L E is equal to $qP = QP - Qq$ or $Qq - QP$. Now if the Angle QCq be ſmall, we have $CE : Cq :: LE : Qq :: QP - Qq : Qq$. And therefore $CE + Cq : Cq :: QP : Qq$. After the ſame way, when Bq is leſs than a Quadrant, $Cq - CE : Cq :: QP : Qq$. When the Planet is near the *Aphelion* or *Perihelion*, C E becomes nearly equal to C S; and C Q + C E is almoſt the ſame with

AS: And therefore QP : Q*q* :: AS : AC, when the Arch A*q* is leſs than a Quadrant; but when B*q* is leſs than a Quadrant, then as SB : CB :: QP : Q*q*. Say as CS : CQ :: R the Radius to a Line L, and then $CQ = \frac{CS \times L}{R}$. Alſo the Radius is to the Coſine of ACQ as SC : CF or CE, which are nearly equal: Wherefore $CE = \frac{SC \times \mathit{Coſine}\ AQ}{R}$, whence we have the Analogy $QP : Qq :: \frac{SC \times L + SC \times \mathit{Coſ.}\ AQ}{R} : \frac{CS \times L}{R} :: L + \text{Coſine } AQ : L$; when AQ is leſs than a Quadrant: But if it be greater than a Quadrant, QP will be to Q*q* :: L − Coſine AQ : L. And in this manner, if there be an Arch taken as A*q*, which is either a little leſs or bigger than the Truth, we ſhall find the Arch AQ, which is to be added or ſubſtracted; ſo that the Area ASQ may be nearly proportional to the Time. And if inſtead of AQ we take another Arch AQ, and argue as in the former Arch, we ſhall have a new A*q* nearer to the Truth: And by this means we ſhall conſtantly approach to the true Arch, ſo that the Difference may be leſs than any given Quantity.

THERE is no need of explaining this Method any farther, we will only illuſtrate it with Examples in the Motions of the Planet *Mars*. In *Mars*'s Orbit the Logarithm B is 0,7244446; and the Longitude L is 1080631 of ſuch parts as the Radius is 100000.

LET us find the Angle ACQ, when the mean Anomaly or Arch proportional to the Time is only one Degree: Becauſe CS is almoſt the 10*th* part of CA. I ſuppoſe AQ to be 0,9 Deg. that is a tenth part leſs than the mean Anomaly. Add the Log. Sine of 0,9 to the Log. B, and the Sum is 8,9205466 = to the Log. of the Number 0,083281; this Number expreſſes the bigneſs of an Arch equal to $SF = NP$: And if the Arch AQ had been rightly aſſum'd, $AN - NP$ had been equal to AQ, and $QP = 0$. But in the preſent Caſe QP is equal 0,01671; from which if I take away its tenth part, becauſe AS is greater than AC by about a tenth part, we ſhall have $Qq = 0{,}01504$, which being added to AQ gives $Aq = 0{,}91504$.

2dly, LET the Arch AN or the mean Anomaly be 2 Degrees; I ſuppoſe the Arch AQ to be 1,83, almoſt double of the former; and adding to its Log. Sine the Log. B, the Sum is 9,2286992, the Log. of the Number 0,16931. And then $QP = 0{,}00069$; from which ſubſtracting a tenth part, Qq is nearly $= 0{,}000063$, and Aq 1,83063, which is not the 10000*th* part of a Degree different from the Truth.

3dly, SUPPOSE the Arch proportional to the Time to be 3 Degrees, I take AQ to be $2{,}745 = 1{,}83 + 0{,}915$; and to its Log. Sine adding the Log. B, we have the Log. of the Number $0{,}25392 = NP$, and $AN - NP = 2{,}74638$, therefore $Qq = 0{,}001$ nearly, and $Aq = 2{,}746$: So that by one Addition of two Logarithms we have the Arch Aq true to the thouſandth part of a Degree.

4thly, NOW if we ſhould not proceed by ſingle Degrees, but were to find the Angle ACQ when the mean Anomaly is much larger; for Example 45°: I make my Suppoſition that the Arch AQ is 40 Degrees, and to its Log. Sine add the Log. B; the Sum is 0,5320121, equal to the Log. of the Number 3,4081, which Number ſubſtracted from 45, leaves $AN - NP = 41{,}5919$, which exceeds the Arch AQ by 1,5919. And therefore if we take as $L +$ Coſine AQ to L, ſo 1,5919 to a fourth, we ſhall have the Arch Qq 1,4865. And therefore $Aq = 41{,}4865$, which does not differ much above the thouſandth part of a Degree from the Truth. But without this proportion we might have found Aq by taking an Arch which is ſomewhat leſs than $AN - NP$, but nearly equal to it. Suppoſe we had made $AQ = 41{,}5$, and adding its Log. Sine to the Log. B, we ſhall have another Arch N P = 3,5132, which ſubſtracted from A N gives 41,4868 for a new A *q*. And this Arch is eaſier found than by the former proportion; and beſides comes nearer to the Truth than the laſt A *q* was.

5thly, AFTER having found A *q* or the Anomaly of the Eccentrick, that anſwers to the mean Anomaly of 45 Degrees; if we ſhould again proceed by ſingle Degrees, by only one Addition of two Logarithms, we may find the Anomaly of the Eccentrick to all the following Degrees of the Semicircle, *viz.* when the mean Anomaly is 46 Degrees I make A Q to be 42,4, and adding its Log. Sine to the Log. B, I find A N — N P 42,4249; to which if I make the new A Q equal, I ſhall have an A *q*, which is not 1000*th* part of a Degree diſtant from the true Anomaly of the Eccentrick. So likewiſe when the mean Anomaly is 47 Degrees, I take A Q 43,36 = to the former A *q* + the Increment that accrues to it by adding a Degree: And adding the Log. B to the Log. Sine of 43,36, the Sum is the Log. of the Number 3,6402, which ſubſtracted from A N leaves A N — N P = 43,3598 equal to a new A *q*: And this Arch is about the 10000*th* part of a Degree different from the true Anomaly of the Eccentrick.

6thly, IF again paſſing over the intermediate Degrees I would find the Arch A *q* when the mean Anomaly is 100 Degrees; I make A Q equal 96 Degrees, and adding its Log. Sine to the conſtant Log. B, the Sum is the Log. of the Number 5,273, and A N — N P = 94,727. Therefore I put again A Q = 94,72, and adding together its Log. Sine and the Log. B, I have the Log. of the Number 5,285, which ſubſtracted from A N leaves A *q* = to 94,715. In like manner when the mean Anomaly is 101 Degrees, I make A Q 95,71; and I find N P to be 5,2756, which ſubſtracted from 101, leaves A *q* 95,7244. And here again, if we proceed by Degrees, we ſhall

Lecture XXIV.

have the Eccentrick Anomaly conſtantly by the Addition of two Logarithms, one of which being conſtantly the ſame, may be ſet once down in a piece of Paper by itſelf, and the Labour ſav'd of frequently tranſcribing it.

Table XXII. Fig. 6.

LET us now paſs to another ſort of Orbit whoſe Eccentricity bears a great proportion to its mean diſtance. For Example, Let us ſuppoſe the *Aphelion* diſtance to be to the *Perihelion* diſtance as 70 is to 1; and ſuch is nearly the Orbit of that Comet which Dr. *Halley* firſt found to compleat its Period in 75 $\frac{1}{2}$ Years. Here A C or C Q the mean diſtance is 35,5, and C S is 34,5 of ſuch parts as S B is 1. And the conſtant Log. B is 1,7457133. We muſt find the Arch B *q* when the mean Anomaly computed from the *Perihelion* is $\frac{1}{100}$ of a Degree. I ſuppoſe B Q to be 0,35: To its Log. Sine add the Log. of B, and the Sum is the Log. of the Number 0,34013, which added to the Arch A N makes ,35013. If this Arch had been only 35, B Q had been rightly taken; but the difference is 0,00013. And therefore becauſe C B is to S B as 35,5 to 1; multiply the difference ,00013 by 35,5, and we ſhall have Q *q* = ,004615, and the Arch B *q* = 0,354615; and the Error leſs than ,0003 of a Degree. Again, let the mean Motion be ,02, I put B Q = 0,71, and adding its Log. Sine and B together, I have the Log. of the Number 0,68998, and B N + N P = ,70998: The difference is 0,00002; which multiply by 35,5, and the Product ſubſtracted from B Q leaves B *q* = 0,7092; and the Error is not greater than the $\frac{1}{10000}$ part of a Degree. If the mean Anomaly be 0,03, I make B Q = 1,06, and adding its Log. Sine to B, I have the Log. of the Number 1,03008, to which add the Arch B N; the Sum is 1,060088, which is greater than B Q: Wherefore if the difference ,00008 be multiplied by 35,5, and the Product added to B Q, we ſhall have B *q* = 1,06284. In the ſame manner when the mean Anomaly is ,04, I ſuppoſe B Q 1,4, and I find P N = 1,3604, to which adding ,04 the Sum is 1,4004; which exceeds 1,4 by ,0004; multiply this difference by 35,5, and the Product will be ,0142 = Qq, and therefore Bq = 1,4142. In all theſe Examples the Errors are very ſmall, ſeldom exceeding the 1000*th* part of a Degree.

LET us now find the Anomaly of the Eccentrick, when the mean Anomaly is one Degree. Here I make BQ = 20 Degrees, and adding its Log. Sine to B, I have the Log. of the Number 19,045, to which adding 1 the Sum is 20,045, and is greater than 20 by ,045. And becauſe in this Example L — Coſine BQ is to L as 1 is to 11,5 nearly: I multiply the difference ,045 by 11,5, and the Product 0,5175 added to BQ makes 20,5175. Therefore 2*dly* I make BQ 20,51, and NP will be 19,5092; to which adding BN the Sum is 20,5092. And therefore if the difference ,0008 be multiplied by 11,5, and the Product ,0092 ſubſtracted from BQ, there will remain Bq = 20,5008.

Laſtly, LET the mean Anomaly be 2 Degrees; I put BQ = 30 Degrees, and then I find NP 27,84; to which adding 2, and the Sum is 29,84, which is leſs than 30 Degrees: Multiply the difference ,16 by 6,3, (for L — Coſine BQ is to L as 6,3 to 1) and we have 1,008 = Qq: And therefore this Arch ſubſtracted from BQ gives Bq = 28,982. Therefore to correct the Error, I put again BQ = 29 Degrees; and by a like proceſs I find Bq = 28,9672. Having found the Angle ACQ, the Angle ASQ is eaſily found. Table XXII. Fig. 5, 6. For in the Triangle QCS we have the ſides QC, CS and the Angle QCS: Therefore we ſhall find the Angle ASQ and the ſide SQ; then ſay as the greater Axis of the Ellipſe is to its leſs, ſo the Tangent of the Angle ASQ is to the Tangent of ASP, which will thereby be found; and it is the coequated or true Anomaly. Again, ſay as the ſecant of the Angle ASQ is to the ſecant of ASP, ſo is SQ to SP the diſtance of the Planet from the Sun. Or perhaps theſe things may be eaſier computed in this manner. Having the Arch AQ, we have its Sine QH and its Coſine HC: But we have SC in ſuch parts as the Radius or CQ is 100000; therefore we have HS. Say as the greater Axis of the Ellipſe is to its leſs, ſo is QH to PH, which will therefore be given. In the Rectangle Triangle PHS, we have alſo the ſides PH and HS, wherefore we can find PSH the true Anomaly, and PS the diſtance of the Planet from the Sun.

BECAUSE in the *Aphelions* and *Perihelions* the points Q and N, or the mean and true place of a Planet coincide; and in the firſt Semicircle of Anomaly the mean place is before the true place, in the ſecond the mean place is behind the true; if we have determined the Poſition of the *Apſides* of the *Earth*'s Orbit, we ſhall know the Time when the true and mean place coincide. For when the Sun is obſerved in that point of the Ecliptick where the *Perihelion* is, then the Earth is in the *Aphelion*. And having this Moment of Time by *Aſtronomical* Tables, we ſhall have the mean Anomaly for any other Time, as likewiſe the Arch AN. For theſe Arches are computed according to the proportion of the Times, and are placed orderly in the Tables. Now having for any point of Time the Arch AN, we have ſhewed, how from thence we may compute the true Anomaly, and the place of the Earth in the Ecliptick, to which the place of the Sun is always oppoſite.

BESIDES the Theory of *Kepler*, according to which the Planets do really regulate their Motions, there is another Elliptick Hypotheſis which has been chiefly improved by two moſt Celebrated Aſtronomers, *Iſmael Bullialdus* and Dr. *Seth Ward*, formerly Profeſſor in this Chair and afterwards Biſhop of *Salisbury*, by whoſe Pains *Aſtronomy* has been much advanced. And ſince this Hypotheſis does not want Elegance, and a neatneſs in Geometry; and beſides it admits of an eaſineſs in computing, we will here briefly explain

Lecture XXIV. explain it. In this Hypotheſis, with *Kepler*, it is ſuppoſed that the Planets Orbits are *Ellipſes*, and that they have all one common Focus in which the Sun reſides. Moreover they ſuppoſe that each Planet does move in the Periphery of its Orbit, in ſuch a manner, that drawing Rays or Lines to the other Focus, they deſcribe Angles proportional to the Times. Theſe things being ſuppoſed Dr. *Ward* ſhews an elegant Method of finding the true Anomaly from the Mean, having determined the Species of the Planet's Orbit; And it is as followeth.

Table XXIII Fig. 2. LET APB be the Ellipſe which the Planet deſcribes, AP the Line of the Apſides, S the Focus in which the Sun is placed, F the other or the upper Focus, which is the Center of equal Motion. Let the Angle AFL be proportional to the time, or be the Mean Anomaly, then L will be the place of the Planet in its Orbit, and the Angle ASL the Co-equated, or true Anomaly. Produce FL to E, ſo that FE may be equal to AP the greater Axis of the Ellipſe; and therefore ſince by the Nature of the Ellipſe FL and LS are equal to the ſame AP, then LE muſt be equal to LS, and the Triangle LSE will be an Iſoſceles Triangle; and therefore the Angles E and ESL are equal, and the exterior Angle FLS being the Sum of both, will be the double of each, or double of the Angle LES. Therefore in the Triangle EFS, having FE and FS, and the Angle EFS, which is the Complement of LFA to two rights, we can find the Angle E, whoſe double is equal to the Angle FLS, which therefore will be known: But the Angle AFL is equal to the two Angles FSL and FLS, and therefore the Angle FLS is the *Proſthaphæreſis* or the Equation, which is to be ſubſtracted from the Mean Anomaly, or added to it, to have the true Anomaly.

IN reſolving the Triangle EFS, having EF and FS, the Analogy is $\frac{1}{2}$ES + $\frac{1}{2}$FS : $\frac{1}{2}$ES — $\frac{1}{2}$FS, that is, as AS to SP :: Tang. $\frac{1}{2}$ AFE : Tangent of $\frac{1}{2}$ difference of the Angles E and FSE; but be-

Lecture XXIV.

becauſe the Angle E is = L S E, F S L is the difference of the Angles E and F S E; wherefore the Angle found by the Analogy being doubled, gives the Angles F S L, which is the true Anomaly. Now the Practiſe here is ectreamly eaſy; for becauſe A S and S P are conſtant Quantities, the difference of their Logarithms is a conſtant Quantity, wherefore a given Number is to be added to Log. Tangent of half the Mean Anomaly, and then we ſhall have the Tangent of half the true Anomaly. Moreover, in the Triangle LFS, having all the Angles and the Side S F, we can find S L the diſtance of the Planet from the Sun.

THIS Hypotheſis of Dr. *Ward*'s is a very uſeful Approximation, and ſerves to ſhorten the Calculation, and make it eaſy: But yet it is ſtill only an Approximation, and does not come up to the Truth: We will here ſhew the reaſon of it. Let A P B be the Orbit of the Planet, A Q B the Circle circumſcribed, the Arch A Q the Anomaly of the Eccentrick, and A N the Mean Anomaly. From the Center C draw N C, and Q G parallel to it; the Angle Q G A is equal to N C A or the Mean Anomaly, and C G will be nearly equal to C S, but a little leſs than it. For from the Focus S on Q C, let fall the Perpendicular S F, which we ſhewed before to be equal to the Arch Q N: But becauſe the Arch Q N is ſmall, its Sine will be almoſt equal to the Arch; and therefore GO a perpendicular on NC, will be nearly equal to S F, but ſomewhat leſs. But the Triangles G O C and S F C are nearly equiangular, (for N C Q the difference of the Angles G C O and S C F is very ſmall,) and therefore becauſe O G is almoſt equal to S F, but a little leſs than it; C G will be almoſt equal to C S, but ſomewhat leſs. The other *Focus* of the Ellipſe then muſt be a little above the Point G, but very near it; and if we draw from the Planet's place the Line P L parallel to Q G, the Point L will be likewiſe above the Point G, but yet not far diſtant from it; and therefore the Point L and the other Focus of the

Plate XXIII. Fig. 3.

Lecture XXIV. Ellipſe do nearly coincide. But the Angle P L A is equal to N C A the Mean *Anomalia*; and the Point L nearly coinciding with the other *Focus*, the Line drawn from P to the other *Focus* will make an Angle with the Axis, nearly equal to the Angle P L A or N C A, that is to the Mean Anomaly. And therefore the Angles at the ſuperior *Focus* are nearly proportional to the times.

WHERE the Angles N C A and Q C A or S C F differ but little from one another, that is, where the Angle N C Q is but ſmall and the Eccentricity, the Points G and L, are nearly coincident with the ſuperior *Focus*. And therefore this Theory is accurate enough to anſwer to the Motion of the Earth, whoſe Orbit is nearly Circular: But in the other Planets, and particularly *Mars* and *Mercury*, it does not do ſo well. And therefore *Bullialdus* from four places of *Mars* obſerved by *Tycho* in the firſt and third Quadrant of Anomaly, found that *Mars* was further advanced in his Orbit than he ought to be by this Theory. But in the ſecond and fourth Quadrants, *Mars*'s true Anomaly was found to be leſs than it ſhould be according to this Hypotheſis: And therefore *Bullialdus* gave it the following Correction. Upon the Diameter A P, which is the greater Axis of the Ellipſis, deſcribe the Circle A D P. Let A F L (Plate XXIII Fig. 2.) be the Mean Anomaly; through L draw the Line Q L G perpendicular to the Axis, meeting with the Circle in Q. Joyn F Q which cuts the Ellipſe in ♈, and ♈ will be the place of the Planet in its Orbit, anſwering to the Mean Anomaly A F L. Now the Angle A F Q, anſwering to the Mean Anomaly A F L, is eaſily found by taking an Angle whoſe Tangent is to the Tangent of A F L, as the greater Axis of the Ellipſe is to the leſſer. And having the Angle A F Q or A F ♈, the Angle A S ♈ is found in the ſame manner as before the Angle A S L was found.

THE Calculations we have here explained: Suppoſe that the Species or Forms of the Orbits are given, as likewiſe their Poſitions. We ſhall afterwards ſhew a way by which the Orbits of the other Planets are determined: But the Form and Poſition of the Earth's Orbit is to be found by the following Methods. Firſt obſerve the Apparent Diameter of the Sun, as likewiſe his Motion; for when the Earth is in its *Aphelion*, the Sun's Diameter is the leaſt of all, and his Motion ſloweſt, the Earth being there at the greateſt diſtance from the Sun. In the *Perihelion*, it coming neareſt the Sun, we ſhall obſerve his Diameter to appear biggeſt. Let any right Line SP repreſent the *Perihelion* diſtance of the Sun: Say, as the Apparent Diameter of the Sun in the *Aphelion* is to its Apparent Diameter in the *Perihelion*, ſo is SP to a Fourth. In SP produced take SD equal to this fourth, and it will be the *Aphelion* diſtance, biſect PD in C, and CS will be the Eccentricity and C the Center. Deſcribe an Ellipſe whoſe *Focus* is S, and greateſt Axis PD, that Ellipſe will be of the ſame Form with the Earth's Orbit, and the Points of the Ecliptick where the Sun's Diameter appears the biggeſt and the leaſt, ſhew the Poſition of the *Apſides*, or the *Aphelion* and *Perihelion*. But becauſe the Diameter of the Sun, in the *Aphelion* and *Perihelion*, is ſcarcely ſeen to alter its bigneſs for ſome Days; it will be very difficult to determine the Poſition of the *Apſides* by Obſervations made on the Apparent Diameter of the Sun only: And therefore it will be better to find out the *Aphelion* and *Perihelion* diſtances and Poſitions by obſerving the Sun's Motion: For the Angular Velocity of the Earth, and the Apparent Motion of the Sun, which is equal to it, is always reciprocally as the Square of the Diſtance, as we have above demonſtrated.

Plate XXIII. Fig. 4.

THEREFORE to determine the Species of the Ellipſe in which the Earth moves, we muſt obſerve the Apparent Velocities of the Sun when it is greateſt and leaſt. Call the leaſt A, and the greateſt B, and let any Right Line SP, repreſent the *Perihelion* diſtance: Say, as A is to B, ſo is SP to another Line C: Produce SP to D, ſo that SD may be a mean Proportional between SP and

Lecture XXIV. and C; this Line SD will repreſent the *Aphelion* diſtance: And therefore if the Ellipſis be deſcribed whoſe *Focus* is S and its greater Axis P D, that Ellipſe will be of the ſame Form with the Earth's Orbit. For becauſe S P, S D and C are continually Proportional, P S Square will be to D S Square, as S P is to C, or as as A to B, that is as the Velocities. Moreover, if the Places of the Ecliptick be diligently marked where the Velocities are greateſt and leaſt, in thoſe Points will the *Apſides* be ſituated. Laſtly, if there be two Places of the Ecliptick obſerved, where the Sun's Apparent Velocities are equal, and the Arch of the Ecliptick between the two places be Biſected, the Point of biſection and its oppoſite, will ſhew the Places of the *Apſides*. But theſe Methods require Obſervations that are very nice and accurate, ſuch as can ſcarcely be made.

FROM the Theory of Dr. *Ward* we have a more certain Method of finding the Form of the Orbit, by three Obſervations of the Sun, and marking the Time between them, which does likewiſe determine the Poſition of the *Apſides*. Plate XXIII Fig. 5. Let A B P D C be the Orbit of the Earth, S the *Focus* in which the Sun is placed, F the other *Focus*: The *Apſides* A and P. Let B, C and D be three Places of the Earth in the Ecliptick, which are found by obſerving three Places of the Sun to which they are oppoſite. At the Center F and diſtance F M, equal to the greateſt Axis of the Ellipſe, deſcribe the Circle M H E L, and let the Lines F B, F C, F D produced, meet with the Circle in the Points G, H, E. Draw likewiſe from the *Focus* S, the Lines S B, S C, S D, as alſo S G, S H, and S E. We have the Angles B S C, B S D and CSD, for they are meaſured by the Arches of the Ecliptick intercepted between the Points obſerved. But according to this Theory, the Earth moves in the Perimeter of an Ellipſe in ſuch a manner, that it deſcribes Angles about the *Focus* F, that are proportional to the Times: And therefore we ſhall have the Angles B F C, B F D, and C F D, taking each of them ſuch that they may have the ſame proportion to four Right Angles, as the times between the Obſervations has to the whole Periodical Time. Moreover, twice the Angle F G S, that is the Angle F B S, is the difference of the Angles A F B and A S B: This we ſhewed before. And the double of the Angle FHS is the difference of the Angles A F C and A S C; the difference of the Angles B F C and B S C, will therefore be equal to 2 F G S + 2 F H S. But becauſe we know the Angles B F C and B S C, we know likewiſe their difference; therefore we have the Sum of the Angles F G S and F H S. But the Angle F G S, is the difference of the Angles BFA and G S A; and the Angle F H S is the difference of the Angles H F A and H S A: Whence both the Angles F G S and F H S will be equal to the difference of the Angles B F C and G S H. But we have the Angle B F A, and the Sum of the Angles F G S and F H S; and therefore we have the Angle G S H. In the ſame manner we can find the Angle GSE. Alſo in the ſame manner the Angle F E S doubled, is the difference of the Angles D F A and D S A; alſo the double of the Angle F H S, is the difference of the Angles C F A and C S A. And therefore twice the Angle F E S — twice the Angle F H S will be equal to the difference of the Angles C F D and C S D; but we have the Angles C F D and C S D: And therefore we have half their difference, that is FES — FHS. But the Angle F E S — F S H is the difference of the Angles C F D and H S E, and we have the Angle C F D; wherefore we have the Angle H S E. We have therefore all the Angles at F, *viz.* B F C, B F D, C F D, and all the Angles at S, *viz.* B S C, B S D, C S D; as alſo G S H, G S E, H S E. Theſe things being laid down.

EXPRESS the Line SH by any Number, *viz.* 100000, and produce E S, till it meets with the Periphery in L, joyn H L, L G and H G. In the Triangle H S L, we have the Angle H S L, the Complement of H S E to two Rights: And the Angle H L S equal to half the Angle H F E, by the 20 *Prop. El.* III. and the ſide H S 100000; wherefore we ſhall find the ſide S L: Then in the Triangle S L G, we have the Angle L S G, the complement of the known Angle E S G to two Rights, and the Angle S L G, being half the Angle E F G, by the 20 *Prop, El.* III. and the ſide S L, therefore we ſhall find S G. And again, In the Triangle S H G, we have the ſides S H and S G, and the Angle H S G; and conſequently we ſhall find the ſide H G, and the Angle S H G. In the Iſoſceles Triangle H F G, we have the Angle H F G and the Baſe H G, wherefore we ſhall find the ſide H F, which is equal to the greater Axis of the Ellipſe; as alſo the Angle G H F, which being ſubſtracted from the known Angle G H S, leaves the Angle F H S known. Laſtly, In the Triangle F H S, having F H and H S and the Angle F H S, we ſhall find the ſide S F, from which ſubſtracting the Angle H S C = F H S, there will remain the Angle CSF, which ſhews the Poſition of the *Apſides.*

THIS Method does ſuppoſe indeed that the Angles at the ſuperior *Focus* be always proportional to the Times, which is not true. But in the Orbit of the Earth, whoſe Eccentricity is ſmall, the Angles that are really deſcribed at that *Focus*, differ ſo little from the Angles that are proportional to the Time, that no ſenſible Error can ariſe from thence, in determining the Species and Poſition of the Orbit.

THE moſt Celebrated *Aſtronomer* Dr. *Edmund Halley*, from whoſe Labours *Aſtronomy* has received great improvements, hath contrived a Method, which depends on no Theory of the Earth's Motion: From which, by Obſervations alone, the Form and Poſition of the Orbit, are to be determined.

Table XXIII Fig. 6.

SUPPOSE the Sun at S, A B C D the Orbit of the Earth, P the Planet *Mars*, who for this purpoſe is to be preferr'd or choſen before the others. Firſt obſerve the true time and place, when *Mars* is in Oppoſition to the Sun, for then the Sun, the Earth and *Mars* are in one Right Line; or if it happens (as it often does) that *Mars* has any Latitude, the Sun, the Earth and *Mars* his Place reduced to the Ecliptick, are in a Right Line. Let the Sun, the Earth and *Mars*, have their Places in the Points S, A and P, in the Right Line S P. Since *Mars* his Period conſiſts of 687 Days, after that time *Mars* will return to the Point P, and ſeen from the Sun he will appear in the ſame Place as before, in which he was ſeen alſo from the Earth: But the Earth does not return to A till after $730\frac{1}{2}$ Days; and therefore when *Mars* is P it will be in B. and will obſerve the Sun in the Line S B, and *Mars* in the Line B P. By obſerving the Places of the Sun and *Mars*, we have all the Angles of the Triangle PBS. And ſuppoſing P S to conſiſt of 100000 Parts, we can find the diſtance S B in thoſe Parts, as likewiſe its Poſition. After the ſame manner, when *Mars* has finiſhed another Period, the Earth will be in C, and we can find the length of the Line S C and its Poſition; and likewiſe by the ſame Method another Line S D and its Poſition may be obtained: And by this means we are come to this *Geometrical* Problem. Having three Lines meeting in the *Focus* of an Ellipſe, all given in Length and Poſition, to find the Length of the Tranſverſe Axis, its Poſition and the diſtance of the *Foci*: which Problem the *Geometers* ſhew how to conſtruct, and we in the following Lectures will likewiſe give its Solution.

LECTURE XXV.

Of the Equation of TIME.

Motion the Meaſure of Time.

ALTHO' *Time* be in its own nature a real Quantity, as being endowed with the chief Properties of Quantity, Equality, Inequality and Proportion; yet for to meaſure this Quantity, we muſt have the Aid and Aſſiſtance of Motion, as a Meaſure to eſtimate and compare the Quantities of *Times*; and therefore *Time*, when it is conſidered as meaſurable, marks out ſome Motion: For if all Things were at reſt, we could by no means know the Flux or Quantity of *Time*, and the Duration of all Things would go on without Perception.

Uniform Motion the proper Meaſure.

BUT becauſe *Time* conſtantly flows equally, and in the ſame manner, for to meaſure it we muſt make uſe of ſuch a Motion, as is in itſelf ſimple, uniform, and always going on at the ſame rate; ſo that the Body which has this Motion, at leaſt as to its Periods, may always keep the ſame force, and yet go thro' equal Spaces in equal *Times*.

The Motions of the Sun & Moon the fitteſt Meaſures.

FOR common uſe we muſt take that Motion which is moſt remarkable, evident to every Body, and plain to common Senſe; ſuch is the Motion of the Stars, and chiefly of the Sun and Moon, which not only, by the common conſent of all Mankind, are agreed upon for this effect, but by the Almighty and wiſe Creator of the Univerſe are eſtabliſhed for this purpoſe: For in the

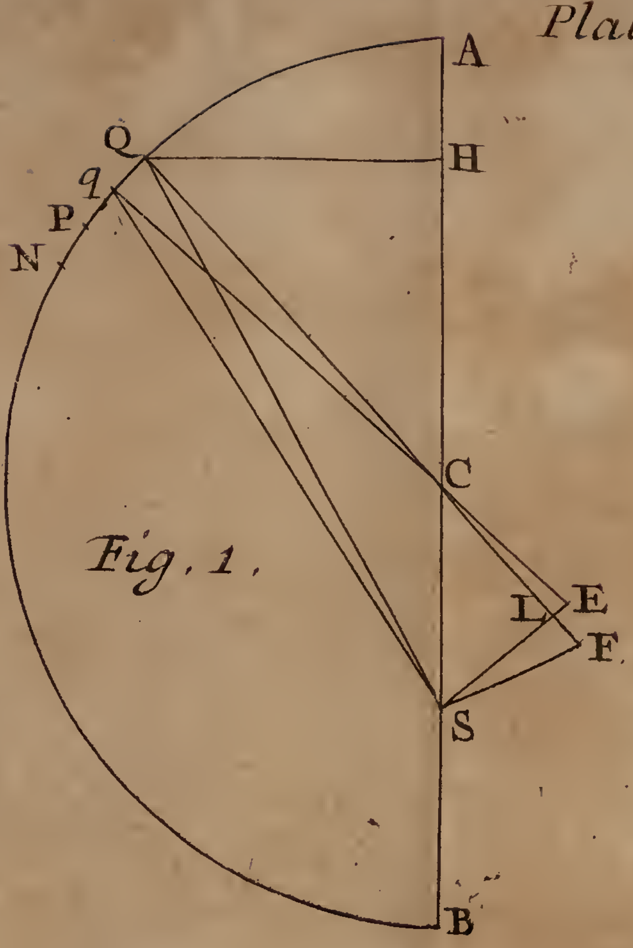


Fig. 1.

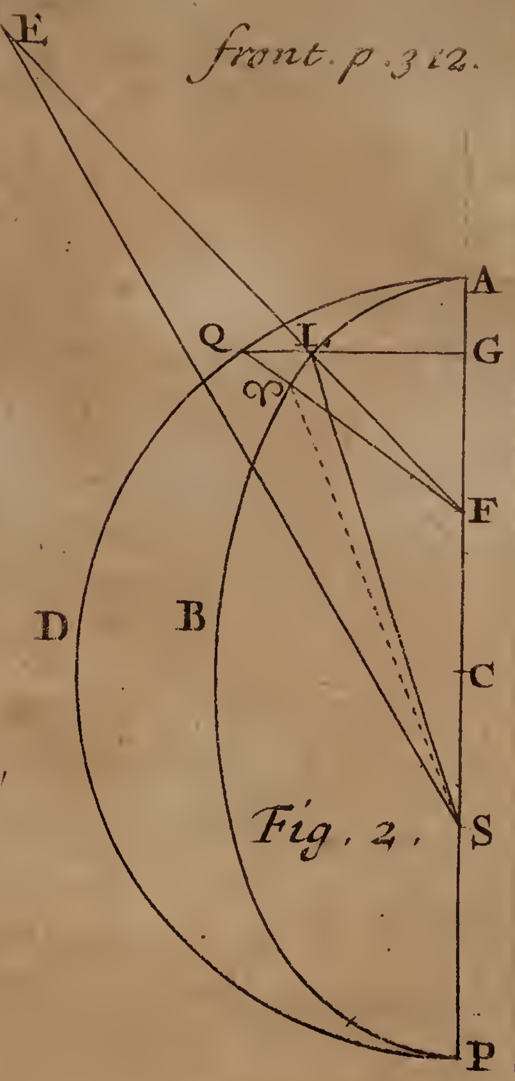


Fig. 2.

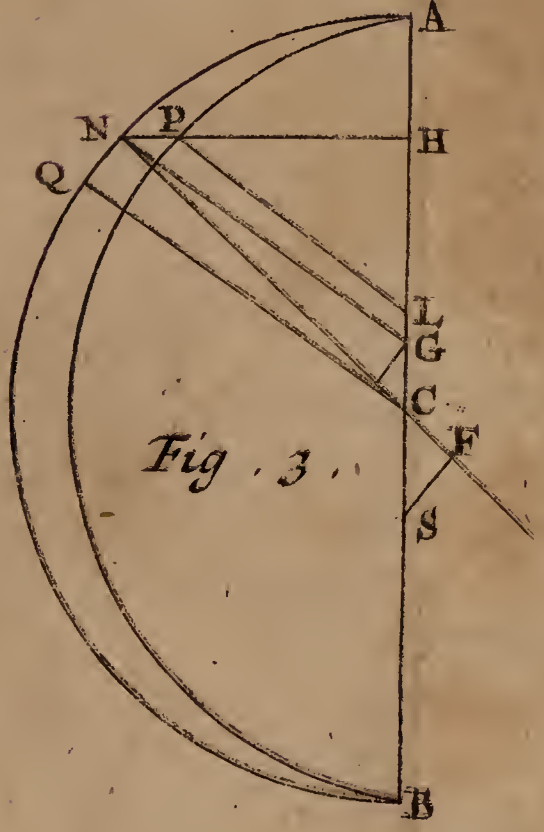


Fig. 3.

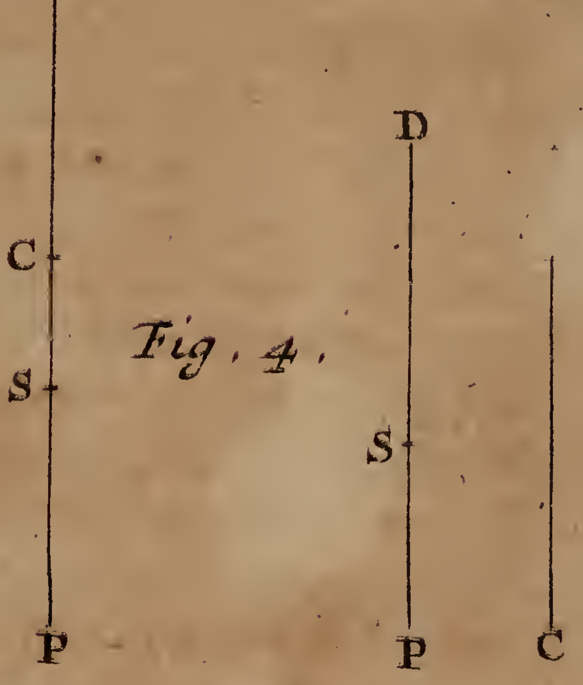


Fig. 4.

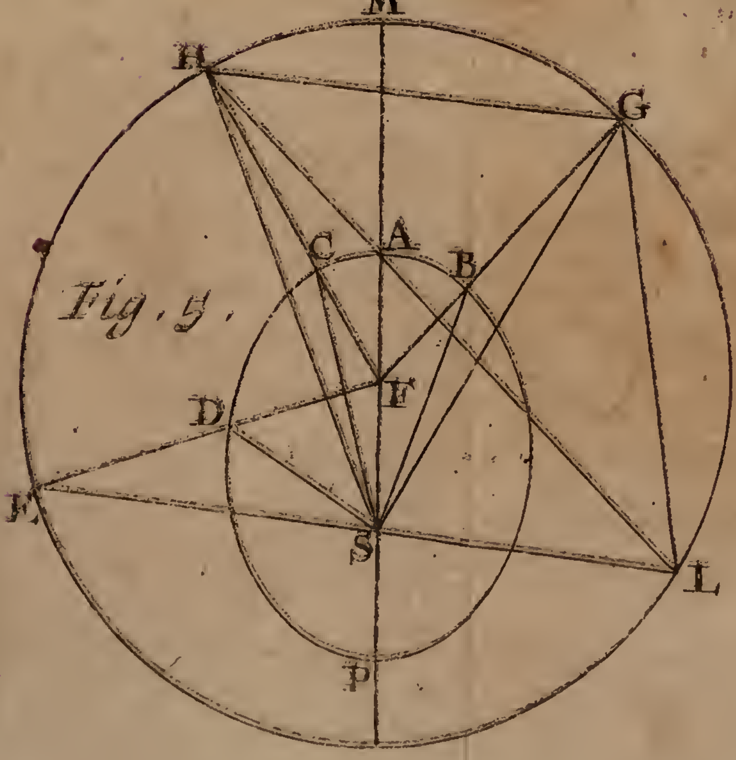


Fig. 5.

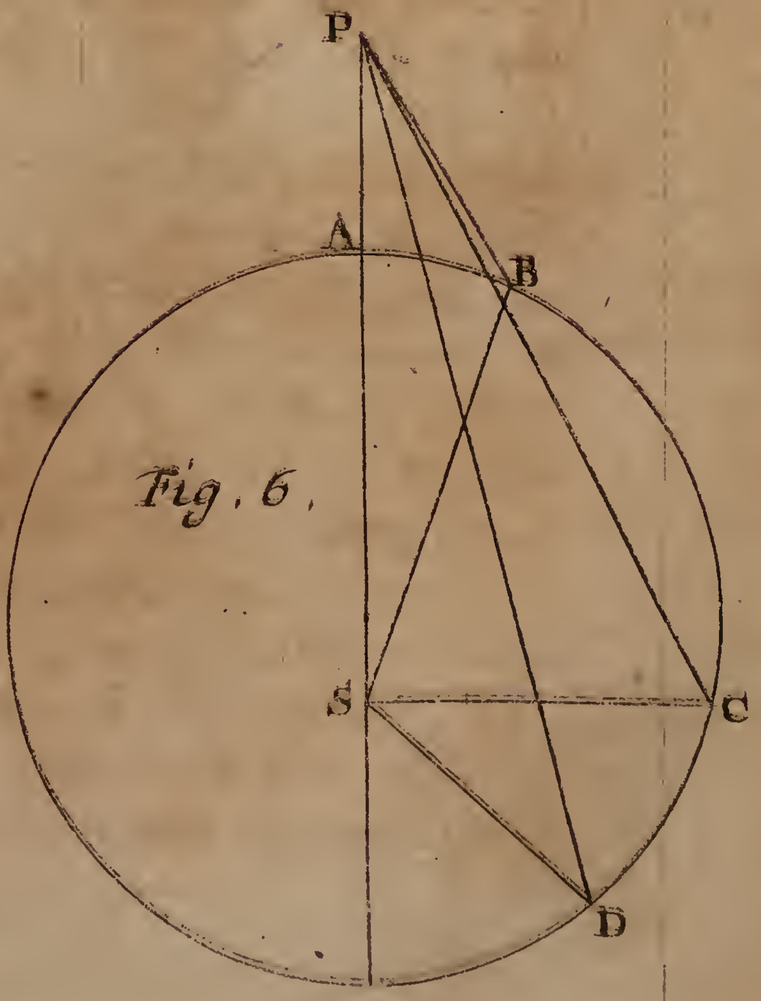


Fig. 6.

the Scriptures we read that God ſaid, *Let there be Lights in the Firmament of the Heaven, to divide the Day from the Night; and let them be for Signs and for Seaſons, and for Days and Years.* And therefore by the Celeſtial Motions, and chiefly by that of the Sun, are the *Times* rightly diſtinguiſhed and marked out. Who therefore dare ſay that the Sun will not tell us Truth! The *Aſtronomers* are the bold Men who tell us ſo; for they by their nice ſearch into Things, have found that the Sun's apparent Motion is no ways equal; they obſerve that he now and then ſlackens his Pace, and afterwards quickens it again: And therefore *Equal Time*, which goes on always at the ſame rate, cannot truly be meaſured by the Sun's Motion.

The diſtinction between the True and Equal Time.

HENCE the *Time* which the Sun's Motion ſhews, and which is called the *Apparent Time*, is different from that *Time* which flows uniformly and always at the ſame Rate, which is called by the *Aſtronomers* the *True and Equal Time*; according to which all the Celeſtial Motions are to be eſtimated regulated and ſettled. For upon the account of the unequal Motion of the Sun, and the Obliquity of the Ecliptick to the Equator, we have neither Days nor Hours perfectly equal, as we ſhall here ſhew.

THE Solar Day is that ſpace of *Time* which paſſes, while the Plane of the Meridian of any place paſſing thro' the Center of the Sun, by the Earth's Revolution turning round its own Axis, returns again to the Sun's Center; or it is the *Time* between one Mid-day and the next which comes after. Now if the Earth had no other Motion but that round its Axis, all the Days would be exactly equal to one another, and to the time of the Revolution round the ſaid Axis. But becauſe while the Earth is whirling round its Axis, it is alſo going forward in its proper Motion Eaſtward; when any Meridian has compleated its Revolution, after having paſs'd the Sun's Center, its Plane will not have then paſſed thro' the Sun, Lecture XXV.

Table XXIV Fig. 1.

Sun, as is plain by the Figure. For let the Sun be S, A B a portion of the Eclipttick; let the Line M D repreſent any Meridian, whoſe Plane produced, paſſes thro' the Sun when the Earth is in A: Let the Earth proceed in its Orbit and come to B, while it has compleated a Revolution round its Axis; and then the Meridian M D will be in the Poſition *m d*, parallel to the former M D; and conſequently will not as yet have paſſed thro' the Sun, nor will the Inhabitants under that Meridian have had their Mid-day. But the Meridian *d m* with its angular Motion muſt ſtill go on before its Plane can paſs thro' the Sun, and muſt deſcribe the Angle *d* B *f*. And therefore all the Solar Days are longer than the *Time* of one Revolution round the Earth's Axis. If the Planes of all the Meridians were perpendicular to the Plane of the Earth's Orbit, and the Earth deſcribed this Orbit with an equal Motion, after any Meridian had compleated its Revolution, becauſe M D and *m d* are parallel, the Angle *d* B *f* would be equal to the Angle B S A, and the Arches A *f* and A B ſimilar: And becauſe the *Times* are always equal, the Arch A B and the Angle *d* B *f* would conſtantly be of the ſame Quantity, and all the Solar Days would be equal to one another; and then the apparent and equal *Time* would agree. But neither of theſe two Caſes have place in Nature; for the Earth does not proceed in its Orbit with an equal Motion; but in its *Aphelion* it deſcribes a leſs Arch, in its *Perihelion* a greater. And moreover the Planes of the Meridians are not perpendicular to the Ecliptick, but to the Equator: And therefore the *Time* of the angular Motion *d* B *f*, which beſides the intire Revolution is to be added to the ſpace of a Solar Day to compleat it, is not always of the ſame quantity; whence the Solar Days will not be equal.

It is proved that the Solar Days are unequal.

The ſame is made plain by the apparent Motion of the Sun.

BUT perhaps this may appear plainer, if we paſs from the real Motion of the Earth and conſider the apparent Motion of the Sun; for it is by his apparent Motion that we meaſure the *Apparent Time.* And therefore you muſt obſerve that the Natural Solar Day is that ſpace of *Time*, in which, by the Revolution of the whole Heavens, which is called the Revolution of the *Primum Mobile* or of the firſt moveable Orb, the whole Circumference of the Equator paſſes through the Meridian; and alſo ſo much more of the ſame Circle as anſwers to the apparent Motion of the Sun to the Eaſt, in the mean while.

The diurnal Arches of the Equator are not equal to the diurnal Arches of the Ecliptick.

BUT the Arch of the Equator paſſing thro' the Meridian, is not always equal to the correſpondent Arch of the Ecliptick which paſſes thro' the ſame in the ſame time; but is ſometimes bigger, and ſometimes leſs than it, even tho' the Sun's Motion were equal in the Ecliptick: The difference between them ariſes from the oblique Poſition of the Ecliptick to the Equator, as is plain by the Figure. Suppoſe ♈ ♋ a Quadrant of the Ecliptick, and ♈ E a Quadrant of the Equator. Suppoſe the Arch ♈ A to be one Degree, which is nearly equal to the diurnal Motion of the Sun in the Ecliptick; for his mean Motion is 59′. 8″. Let A B be an Arch of the Circle of Declination paſſing thro' the Sun in A, and intercepted between the Equator and the Ecliptick. In the right angular Triangle ♈ B A, having the ſide ♈ A 1 Degree, and the Angle A ♈ B, which is the Inclination of the Ecliptick to the Equator, and is nearly 23½ Degrees, we ſhall find the ſide ♈ B 55′. 1″, almoſt 5′ leſs than the Arch ♈ A. Again, ſuppoſe the Arch of the Ecliptick ♈ C 89°. From thence we ſhall find the Arch of the Equator ♈ D 88°. 54′. 34″; but when the Arch of the Ecliptick ♈ ♋ is 90 Degrees, then A E, the correſpondent Arch of the Equator, is alſo 90 Degrees. And the difference of the Arches ♈ C, ♈ D is 1°. 5′. 26″. And the difference of the Arches of the Equator ♈ B and D E is 10′. 25″, altho' the Arches of the Ecliptick ♈ A and C ♋ which anſwer to them are equal. From which it is evident, that the Arches of

Table XXIV Fig. 2.

of the Equator anſwering to equal Arches of the Ecliptick are unequal: And therefore the diurnal Arches of the Equator which paſs through the Meridian are unequal; but they meaſure the Solar Days: Wherefore the Solar Days are unequal.

The ſecond Cauſe of the Inequality of Days.

BUT the Obliquity of the Ecliptick is not the only Cauſe of the Inequality of Days; for the very apparent Motion of the Sun in the Ecliptick is unequal; for he proceeds more ſlowly, and ſtays longer in the Northern Signs than in the Southern, by eight intire Days: And therefore if there were no Obliquity of the Ecliptick, by this cauſe alone the diurnal Arches of the Equator could not be equal. And therefore their Inequality will be much greater, upon account of theſe two Cauſes concurring together; that is, the unequal Motion of the Sun, and the Obliquity of the Ecliptick, which tho' they are ſometimes contrary to each other, and ſo diminiſh the Inequality; as it happens when the Arches of the Equator decreaſe on the account of the Obliquity of the Ecliptick, but by reaſon of the Sun's approaching the *Perigæon* they increaſe, and on the contrary: Yet ſometimes theſe two Cauſes concur to increaſe the Inequality, and neither of them depend one on the other, but each of them by itſelf has its Effect.

SINCE therefore the apparent Motion of the Sun to the Eaſt is unequal, it cannot be a fit meaſure of *Time*, which ſhould always go on at the ſame rate. And therefore the natural and apparent Days are no ways to be applied to meaſure the Celeſtial Motions, which do not depend upon the Motion of the Sun: Therefore the *Aſtronomers* found it neceſſary inſtead of theſe Solar Days to ſubſtitute in their place others that were equal, and a mean between the ſhorteſt and the longeſt; and by them to diſtinguiſh the Celeſtial Motions. And when theſe Motions have been computed according to the *Equal Time*, it is neceſſary to turn that *Time* again into the *Apparent Time*, that theſe Motions may be obſerved by us who meaſure and number our *Times* by the apparent Motion of the Sun. And on the contrary, if any Appearance in the Heavens, as for Example, an Eclipſe were obſerved according to the *Apparent Time*, and according to it the *Aſtronomical* Tables were to be examined, to ſee if they did agree with it or not; it will be neceſſary to turn the *Apparent Time* into *Equal Time*, otherwiſe the obſerved *Phænomenon* will differ from that which is found by Computation.

BECAUSE we know no Body in Nature which preſerves conſtantly a perfect uniform Motion; and yet ſuch a Motion is only proper to meaſure equal Days and Hours: It is convenient to imagine ſome Body or Star which moves in the Equator Eaſtward, and which never quickens or ſlackens its pace, but goes thro' the Equator in preciſely the ſame time as the Sun finiſhes his Period in the Ecliptick. The Motion of ſuch a Star will rightly repreſent equal Time, and its diurnal Motion in the Equator will be daily 59′. 8″, the ſame as is the mean Motion of the Sun in the Ecliptick: And therefore the equal and middle Day is to be determined by the arrival of this Star to the Meridian, and is equal to the Time in which the whole Circumference of the Equator or 360 Degrees paſs the Meridian; and beſides that 59′. 8″: And becauſe this Addition of 59′. 8″. always remains the ſame, all theſe mean Days will be conſtantly equal to each other.

SINCE the Sun goes unequally Eaſtward according to the Equator, ſometimes it will come to the Meridian ſooner than this imaginary Star, and ſometimes he will touch it later than it does, and the difference is that which is between the *True* and *Apparent Time*. And this difference is known by having the place of the imaginary Star in the Equator, and the point of the Equator which comes to the Meridian with the Sun; for the Arch intercepted between them being converted into *Time*, ſhews the difference between *Equal* and *Apparent Time*, which is called the *Equation of* Time.

The Equation of Time.

of Time. And it is the *Time* that flows, while the Arch of the Equator intercepted between the point determining the Right-Aſcenſion of the Sun, and the place of the imaginary Star paſſes the Meridian.

Table XXIV Fig. 3, 4.

The Equation of Time *conſiſts of two parts.*

LET ÆQ be a portion of the Equinoctial, EC of the Ecliptick, in which imagine S to be the place of the Sun, SA a Circle of Declination paſſing thro' the Sun, and meeting with the Equator in A, which will be the point which comes to the Meridian with the Sun. Suppoſe *m* to be the place of the imaginary Star which performs its Period in the Equator with an equal Motion: And when the Sun has arrived at the Meridian our imaginary Star will be diſtant from it, by the Arch *m* A; and if the point *m* be Eaſtward of the point A, it will come later to the Meridian than it, and the apparent *Time* will be faſter than the mean; but if the place of the Star *m* be more Weſterly than A, it will ſooner arrive at the Meridian, and the *Apparent Time* is flower than the mean. And the Arch of the Equator A *m* converted into *Time* is the Equation, which being added to or ſubſtracted from the *Apparent Time* gives the true, according as the point *m* is to the Eaſt or Weſt of the point A; and then we have the true *Time*. For to know the poſition of the point A in reſpect of *m*, and the Quantity of the Arch A *m*, take in the Equator the Arch ♈ *s* or ♎ *s* equal to the ♈ S or ♎ S in the Ecliptick; and then the Arch *s m* will be the diſtance between the true and mean place of the Sun, which therefore is given by the Sun's Anomaly; but the Arch A S is the difference between the *Hypothenuſa* ♈ S of the Right-angled Triangle ♈ S A, and its ſide or Baſe ♈ A, which may be found by *Trigonometry*. Moreover, the Arch A *m* is equal to either the Sum or Difference of the Arches A *s* and *s m*; and therefore when they are known, the Arch A *m* will be likewiſe known.

MOREOVER we muſt obſerve, that in the firſt and third Quadrant of the Ecliptick, the point *s* falls upon the Eaſt ſide of the point A: And therefore the Arch A *s* being turned into *Time*, is to be ſubſtracted; becauſe the point S comes later to the Meridian than the point A does. But in the ſecond and fourth Quadrants the point *s* is more Weſterly than A, and arrives at the Meridian before it: And therefore the Arch A *s* turned into *Time* is to be added, for to get the *Time* when the point S arrives at the Meridian. Suppoſe for Example A *s* be two Degrees, as it is when the Sun is in the 20*th* Degree of ♈; this Arch turned into *Time* is 8 Minutes: And therefore we muſt add 8′ to the *Apparent Time*, for to have the *Time* when the point S comes to the Meridian.

MOREOVER in the firſt Semicircle of Anomaly, that is while the Sun in this preſent Age goes from the ſeventh Degree of ♋ to the ſeventh of ♑, the mean Motion of the Sun is greater than its true Motion; therefore then the middle place precedes the true place. And therefore in all that Semicircle the point *m* will be to the Eaſt of the point *s*; and the Arch *m s* turned into *Time*, is to be ſubſtracted from the *Time* that the point S reaches the Meridian: But in the other Semicircle of Anomaly, after the Sun has left the *Perigæon*, or rather the Earth the *Perihelion*, the mean Motion is leſs than the true, and then the mean place follows the true; and conſequently the point *m* is to the Weſt of the point S, and comes ſooner to the Meridian than it does: And therefore the Arch *m s* turned into *Time*, is to be added to the *Time* in which S touches the Meridian. Having now the diſtance of *Time* between the coming of the point *m* to the Meridian, and the coming of the point S to the ſame; as alſo the diſtance of *Time* between the arrivals of the points *s* and A to the Meridian, we ſhall have the diſtance of *Time* between the coming of the point *m* to the Meridian, and of the point A's arrival to the ſame; that is, we ſhall have the difference between the *Apparent and True Time*, which is the *Equation of Time*.

Two Tables for equating Time.

FOR the equating of *Time* the *Aſtronomers* compoſe two Tables, one for the Arch *s m*, which is to be entered into with the Anomaly of the Sun: And if the point *m* be Weſtward of the point *s*, they mark it with + or the Sign of Addition; but if it be on the other ſide, they place — or of Subſtraction. The other Table is for the Arch *s* A, which is the difference between the place of the Sun in the Ecliptick and his Right-Aſcenſion. And the Equations of this Table are likewiſe marked with the Signs of Addition or Subſtraction; as the point *s* is to the Weſt or Eaſt of the point A. The Sum of theſe two Equations, if they be of the ſame kind, that is, both to be added or both to be ſubſtracted; or their difference, if their Affections be of different kinds, make up the abſolute *Equation of Time*.

The Temporary Table.

THE Artiſts likewiſe make a Table compoſed of both the former; but it will only ſerve for a time: Yet it may be uſed for a whole Age without any ſenſible Error; for the ſame Degree of Anomaly keeps nearly in the ſame Degree of the Ecliptick the ſpace of an Age: And therefore for the ſpace of 50 Years theſe two Equations may be joined in one. But becauſe of the Præceſſion of the Equinoxes, the Sun's *Apogæon* in proceſs of Time changes its place in the Ecliptick, and goes Eaſterly with the Fixed Stars: And therefore in different Ages the ſame Degrees of Anomaly will fall upon different Degrees of the Ecliptick: And therefore one Table will not ſerve for all Ages.

When the Solar Days begin to be longer than the mean.

THE imaginary Star, by whoſe equal Motion we meaſure Time, goes conſtantly and uniformly forward to the Eaſt: But the point A which determines the Right-Aſcenſion of the Sun, and marks out the apparent Time, has as it were a Libration, or goes backwards and forwards in reſpect of *m*: Sometimes it gets to the Eaſt of *m*, and ſometimes is to the Weſt of it, and ſometimes coincides with it. And therefore when the point A has its relative Motion in reſpect of *m* Eaſtward, the point A is more Eaſt than the Star *m*, and then the Days are longer than the mean Days, which are meaſured by *Equal Time*; and the faſter the point A goes to the Eaſt, ſo much the longer are the Solar Days: For beſides the Revolution of the whole Heavens, the Arch to be added to make up the Solar Day is greater, becauſe the point A goes a greater ſpace Eaſtward. Hence it follows, that as ſoon as the relative Motion of the point A begins to be Eaſtward, the Solar Days begin likewiſe to be longer than the mean Days. I ſpeak of the relative Motion in regard of the point *m*; for the abſolute Motion of A is always Eaſtward: But when the point A is gone its fartheſt diſtance from *m* to the Eaſt, then it begins to come back again to *m*, and has its relative Motion Weſtward: But before that, the point A will be for a while ſtationary in reſpect of *m*, in the middle Time between its Receſs and Acceſs; and then the Solar Days will be equal to the mean Days; and in theſe Points the Equations will be greateſt. When the Motion of the point A to the Eaſt is quickeſt, there the Days become the longeſt; and where it is the ſloweſt, that is, where the Motion relative to *m* is Weſtward and greateſt, there the Days are ſhorteſt. In the preſent Age wherein we live, when the Sun is in the 10*th* Degree of *Scorpio*, the point A is at its fartheſt diſtance from *m* to the Weſt of it; and its diſtance then amounts to 4°. 2′. 45″, and therefore the greateſt *Equation* in Time is 16′. 11″. From thence the Days begin to encreaſe, till the Sun comes to 22½ Degree of *Aquarius*, where it has gone to its fartheſt diſtance from *m* Eaſtward, it being there removed 3 Deg. 42½ Min. whence the greateſt *Equation* of Time is 14′. 50″: And from thence the relative Motion of the point A be-

When the mean and Solar Days are equal.

At what times of the Year the Equations are greateſt.

gins again to be Weſtward, till the Sun comes to the 24*th* Degree of *Taurus* or the *Bull*; and there the point A is removed from *m* 1 Deg. $1\frac{1}{2}$ Min. to the Weſt of the Star *m*, and the greateſt *Equation* of Time is 4′. 6″. Thence it returns again to *m*, and moves Eaſterly, till the Sun comes into the $3\frac{1}{2}$ Degrees of the *Lion*, where A is diſtant from *m* 1 Deg. $28\frac{1}{2}$ Min. and the greateſt *Equation* of Time is 5′. 53″: And from thence its Motion begins to be to the Weſt, till the Sun arrives at the 10*th* of the *Scorpion*; and thereabouts it changes its Courſe and goes Eaſtward. It is plain, that when the Points A and *m* coincide, that there the mean and *Apparent Time* muſt likewiſe coincide. Hence if we have a Pendulum Clock accurately and nicely fitted, and the Motion of the Hand ſet to equal or *True Time*, the Hand of this Clock will always point out the *Time* different from the Solar *Time* ſhewed by a Sun-Dial; except four times a Year, which is about the 4*th* of *April*, the 6*th* of *June*, the 20*th* of *Auguſt*, and the 13*th* of *December*. At all other Times the Hour by the Sun-Dial will either be before or later than that ſhewed by the Hand of the Clock: And about the 23*d* of *October* the Clock will differ moſt of all from the Sun, where its Motion is ſlower than the Solar *Time* by 16′. 11″.

IF you inquire in what Points the *Equations* are the greateſt, the eminent Dr. *Edmund Halley*, who for his great Inventions is never to be mentioned by *Aſtronomers* without Honour, has given us the Solution of this *Problem*. But to underſtand it we muſt firſt lay down the following *Lemma*.

LEMMA.

IF any plain Figure be projected Orthographically on a Plane; which is done by letting fall from every point of it Perpendiculars on the Plane of Projection; the Area of that Projection of the Figure will

will be to the Figure projected, as the Co-ſine of the Inclination of the Planes is to the Radius.

FOR any Figure can always be reſolved into Parallelograms or Triangles, whoſe Baſes are parallel to the common Section of the Planes; and therefore they will be parallel to the Plane on which they are projected: Wherefore the Baſes of theſe Parallelograms or Triangles, and their Projections on the Plane, are always equal to each other, and parallel, as we have ſhewed in *Lecture* XIII. But the Perpendiculars let fall from the Summits or Tops of the Triangles and Parallelograms upon the Baſes, are alſo perpendicular to the common Section of the Planes, by the *29th* of the firſt *El.* And therefore the Inclination of the Perpendiculars to the Plane is equal to the Inclination of the Planes to each other. And conſequently, the Projections of theſe Perpendiculars will be to the Perpendiculars themſelves, as the Co-ſine of the Inclination of the Plane is to the Radius. Wherefore every Parallelogram or Triangle is projected into another, whoſe Baſe is equal to the Baſe of the Triangle or Parallelogram projected; and its height is to the height of the Figure projected as the Coſine of the Inclination of the Planes is to the Radius. But Triangles and Parallelograms whoſe Baſes are equal, are as the Perpendiculars let fall from the Tops upon the Baſes. The Projection therefore of each Triangle is to the Triangle projected in a conſtant and given proportion; conſequently all the Projections of all the Triangles or Parallelograms are to the Figures projected in the ſame Proportion; that is, the Projection is to the Figure projected as the Co-ſine of the Inclination is to the Radius.

IF the Orbit of the Earth be Orthographically projected on the Plane of the Equator, by letting fall from each of its Points Perpendiculars, the Projection will be an Ellipſe, in whoſe Perimeter the Extremity of a Right Line let fall from the Earth, perpendicular to the Plane of

Lecture XXV.

Plate XXIV. Fig. 5.

the Equator, will conſtantly move: And this point by its Motion will mark out the Right-Aſcenſion of the Earth, or its Motion according to the Equator, as it is to be ſeen from the Sun; to which the Right-Aſcenſion of the Sun ſeen from the Earth is always equal. Let ♈ A ♎ C be the Ellipſe in which the Orbit of the Earth is projected, S the point of Projection of the Sun's Center, ♈ S ♎ the common Interſection of the Equator and the Ecliptick, A any point, where a Perpendicular from the Earth meets with the Projection: The Angle ♈ S A will meaſure the Right-Aſcenſion of the Sun. Now I ſay that this point A which marks out the Motion of Right-Aſcenſion, will ſo proceed in the Ellipſe ♈ A ♎ C, that it will deſcribe about the point S Elliptick Area's proportional to the Times. For in a given Time let A move thro' the Elliptick Arch A B; draw the Lines A S and B S; and the trilinear Figure A S B will be the Projection of the correſpondent Area which the Earth deſcribes in the Plane of the Ecliptick, in the ſame Time, round the Sun: And therefore the Projection A S B will be to the correſpondent Area in the Earth's Elliptick Orbit, as the Co-ſine of the Inclination of the Equator and the Ecliptick is to the Radius. But in the ſame Proportion is the whole Elliptick Area ♈ A ♎ C to the whole Area of the Earth's Orbit: Therefore by Permutation of Proportion, the trilineal Figure A S B will be to the whole Elliptick Area ♈ A ♎ C, as the Area deſcribed in the Earth's Orbit round the Sun is to the whole Area of the Earth's Orbit; that is as the Time in which that Area in the Orbit of the Earth, or the Area A S B in the Projection, is deſcribed, is to the whole Periodical Time. Therefore the point A moves in the Perimeter of the Ellipſe at ſuch a rate, that it deſcribes about S Area's that are continually proportional to the Times.

THE ſame things being laid down; at the Center S and diſtance S A, which is a mean propor-

Plate XXIV. Fig. 6.

proportional between half the greater and half the leſſer Axis of the Ellipſe, deſcribe a Circle; this Circle will be equal to the whole Elliptick Area; as it is eaſy to demonſtrate from the Doctrine of the *Conick Sections*: This Circle will cut the Ellipſis in four Points E, F, G, H. The points of Interſection ſhew the Right-Aſcenſions of the Sun, where the Equations are greateſt. Imagine a point M to move uniformly in the Periphery of the Circle; its Motion will then repreſent the Motion of our imaginary Star *m*, and will deſcribe about the point S circular Sectors that are proportional to the Time: And becauſe the Area of the whole Circle and the Area of the Ellipſe are equal, the Area's of the Elliptick Sectors and of the Circular Sectors, deſcribed in the ſame time, will be conſtantly equal. Let us now ſuppoſe that the point M in the Periphery of the Circle, and the point that marks out the Sun's Right-Aſcenſion in the Ellipſe, be placed at the ſame time both in the right Line S L M. Let theſe Points afterwards be in *m* and A, then the Elliptick Area L S A will be equal to the circular Sector M S *m*: And becauſe the Arch M *m* is without the Ellipſe, the Angle M S *m* will be leſs than the Angle M S A, and the difference of the Angles meaſured by the Arch *m* A, which is the *Equation of Time.* When the point which marks out the Right-Aſcenſion of the Sun comes to the Interſection F of the Circle and Ellipſe; there its angular Motion round the Sun will be equal to the angular Motion of the point *m*; for the Area's *m* S *n* and A S F are equal, they being both deſcribed in the ſame Moment of Time, and at the ſame diſtance from S; and conſequently the Arch *q* F is equal to the Arch *m n*. In the point therefore F, the Motion of Right-Aſcenſion is equal to the Motion of the imaginary Star, or equal to the mean Motion. The ſame thing may be ſhewed at G, H and E: But it was ſhewed before, that where the Motion of Right-Aſcenſion was equal to the Motion of the point *m*, that there the Equations are greateſt. Wherefore in the points F, G, H and E are the Equations greateſt.

Which are the points of the Ecliptick where the Days are longeſt and where ſhorteſt.

Plate XXIV. Fig. 7.

IF you inquire in what points the Days are longeſt or ſhorteſt, the ſame eminent Dr. *Halley* has alſo given us a Geometrical Solution of this *Problem.* Let ♈ ♋ ♎ ♑ be the Ellipſe into which the Earth's Orbit is projected, and S the point of the Sun's Center, K the Center of the Ellipſe. Produce K S on each hand, ſo that K G and S H may be to K S (which is the Projection of the Eccentricity) as the ſquare of the Radius is to the ſquare of the Sine of the Obliquity of the Ecliptick: Thro' K draw ♈ ♎ parallel to the common Section of the Equator and Ecliptick, and cut it at Right-Angles with the Line ♋ K ♑: Thro' G draw G F, and thro' H draw F H parallel to the Lines ♋ ♑ and ♈ ♎; and thro' S and K deſcribe the Hyperbola A B whoſe Aſymptots are F G, F H. This Hyperbola and its oppoſite C D will cut the Ellipſe in the points that are required; that is, when the Sun is in the points of the Ecliptick which correſpond with B and D, then the Days are the longeſt; and in B the Days are longer than in D: But the points of the Ecliptick which anſwer to A and C, give us the places where the Days are ſhorteſt. The Demonſtration of this depends on the Motion of the point that marks the Right-Aſcenſion of the Sun round S; for it deſcribes about it Area's that are proportional to the Times. Therefore the angular Velocity is every where reciprocally as the ſquare of the diſtance from S; conſequently the Velocities muſt be greateſt where theſe diſtances are leaſt; that is, where the leaſt Lines that can be drawn from S fall upon the Ellipſe; and the Velocities are the leaſt where the Lines drawn from S to the Ellipſe are the greateſt: But by the Conſtruction, and the *62d Prop. Lib.* V. of *Apollonius*'s *Conicks*, it is evident that the Hyperbola's will cut the Ellipſis in the points A and C; where the Right Lines S A and S C are the greateſt; and in the points B and D, where the Right Lines S B and S D are the leaſt: For in theſe points the Lines S A, S B, S C, S D are perpendicular to the Curve. Hence the Motion of the Sun, according to his Right-Aſcenſion, will be quickeſt in B and D; and therefore the Days will be then the longeſt: And the Motion being ſloweſt in C and A, the Days will be there the ſhorteſt.

LECTURE XXVI.

Of the Theories of the other Planets.

AFTER having explained the Theory of the Earth's annual Motion, and ſhewed the Methods by which the Form of its Orbit, and the Poſition of the *Apſides* are determined, we may then by the help of *Aſtronomical* Tables compute for any time the place of the Earth in the Ecliptick ſeen from the Sun, and its oppoſite point in which the Sun appears to be, as he is obſerved by us. We will now come to explain the Theories of the other Planets, the knowledge of which cannot be attained without the Earth's Motion being perfectly known.

[*The Heliocentrick and Geocentrick place of a Planet that is in Oppoſition to the Sun coincide.*

BUT the Periods of the Planets or the Times they take to compleat their Circulations are to be found out in the firſt place. For which purpoſe we muſt obſerve, that when any ſuperior Planet comes to an Oppoſition with the

Sun, they then appear in the ſame point of the Ecliptick ſeen from the Earth, as they would do if the Eye were in the Sun and obſerved them from thence; as alſo the inferiour Planets when they are in Conjunction with the Sun, and are obſerved in the Sun's Disk: If there were an Obſerver in the Sun, he would ſee them in the oppoſite point of the Ecliptick in which we behold them: And therefore when ever a ſuperiour Planet is in Oppoſition to the Sun, his Heliocentrick and Geocentrick places coincide: But when an inferior Planet is in Conjunction with the Sun, and is ſeen in his Disk, the Heliocentrick and Geocentrick Places are oppoſite to each other. Moreover in the inferiour Planets, when they are at their greateſt Elongations from the Sun, the Angle at the Sun's Center, contained between the Right Lines drawn to the Earth and Planet, is nearly the Complement of the Elongation: For in Orbits which are nearly circular, a Line touching the Orbit is almoſt perpendicular to the Line drawn from the Sun to the point of Contact: And therefore that Angle will be given. But we have the point of the Ecliptick in which the Earth is at that time ſeen from the Sun; and conſequently the point of the Ecliptick in which the Planet is ſeen from the Sun. And therefore in theſe Poſitions we have the Heliocentrick places of the Planets.

How to find nearly the Periodical Time of a Planet.

IF then any ſuperiour Planet, as for Example, *Jupiter* were obſerved when he is in Oppoſition to the Sun: And again, if he were likewiſe obſerved when he comes next in Oppoſition to the Sun, we ſhall have that Arch which the Planet ſeen from the Sun has in the mean time deſcribed. Say as that Arch is to the whole Circumference, ſo is the time between the Obſervations to a fourth, which will be nearly the Periodical Time of the Planet. After the ſame manner, by obſerving two Heliocentrick places of an inferiour Planet, we may nearly collect its Periodical Time. I ſay nearly, and not exactly; for

front. p. 328.
Plate XXIV

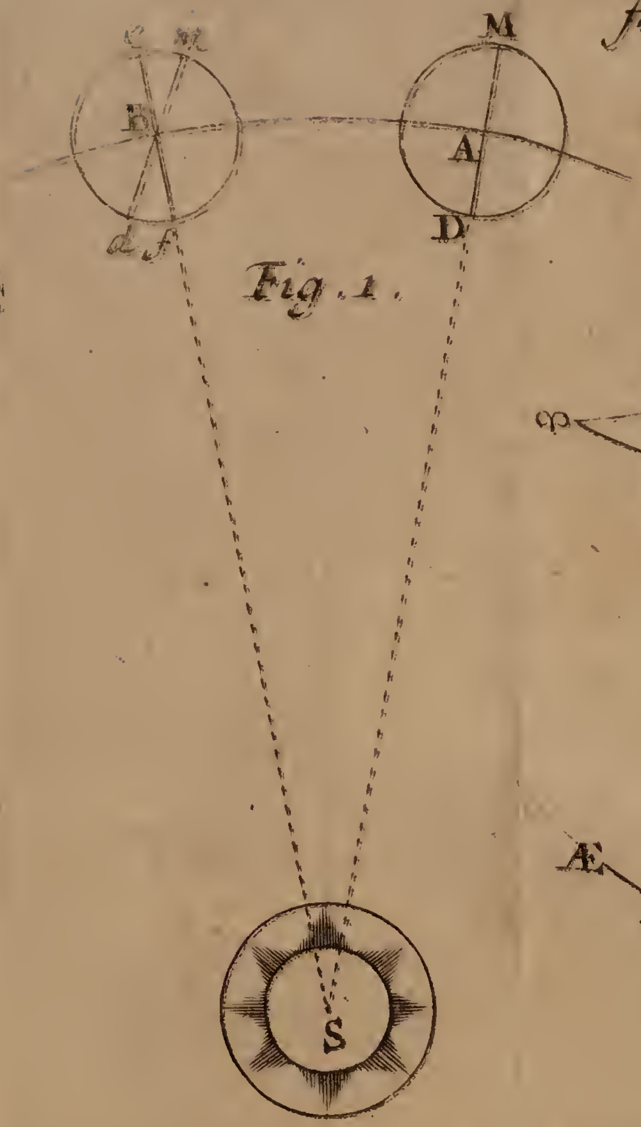


Fig. 1.

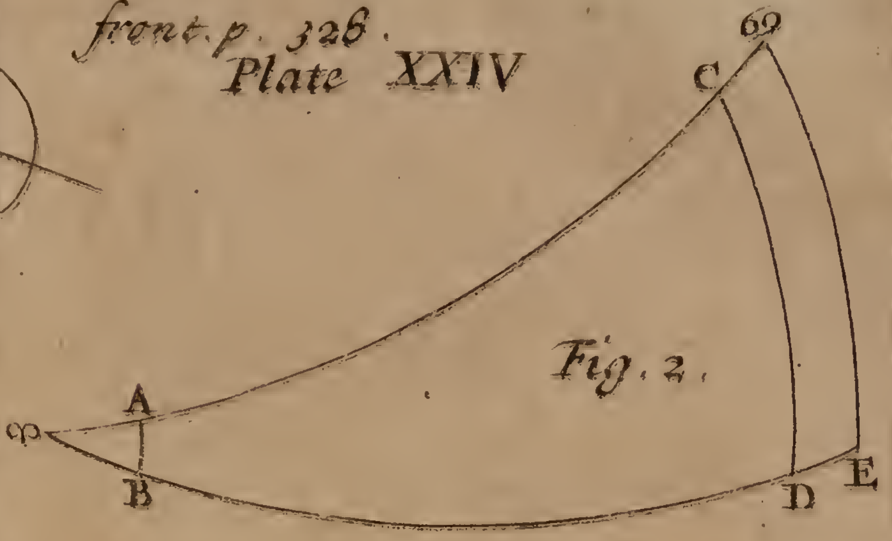


Fig. 2.

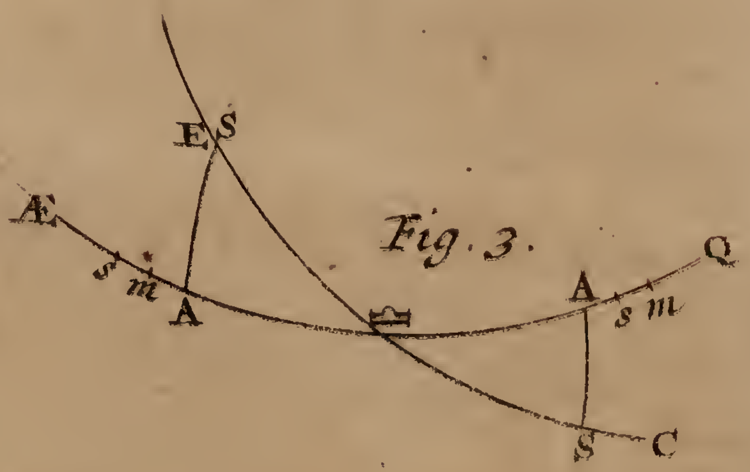
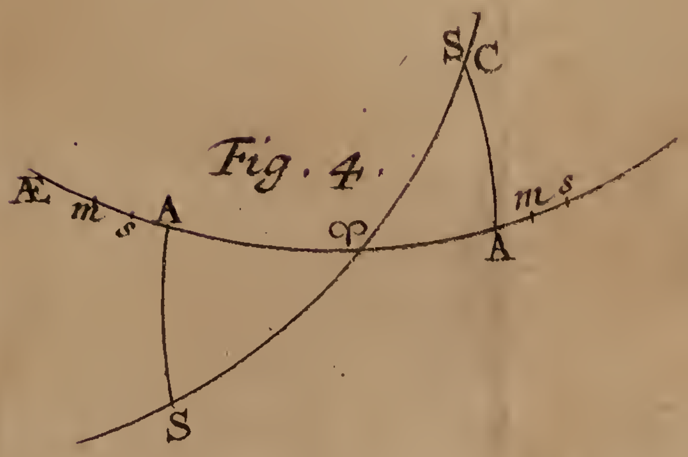


Fig. 3.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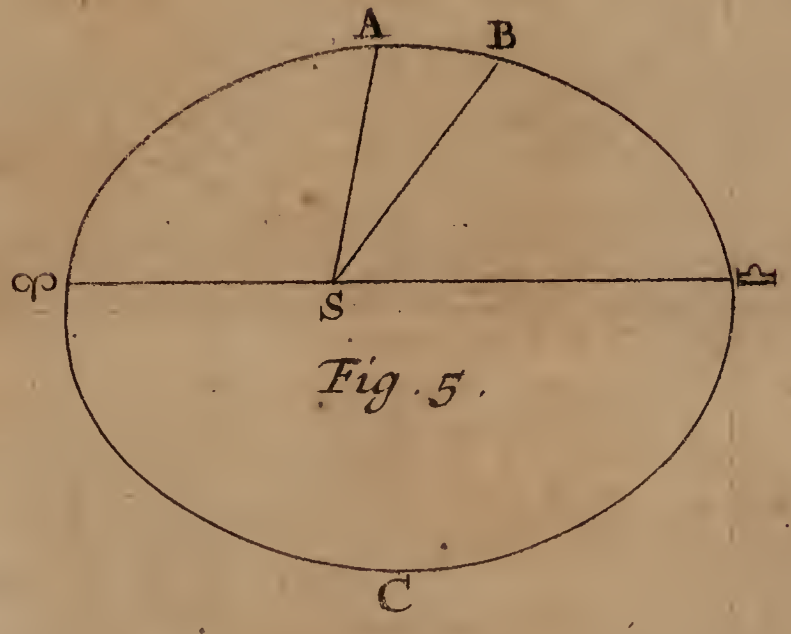


Fig. 5.

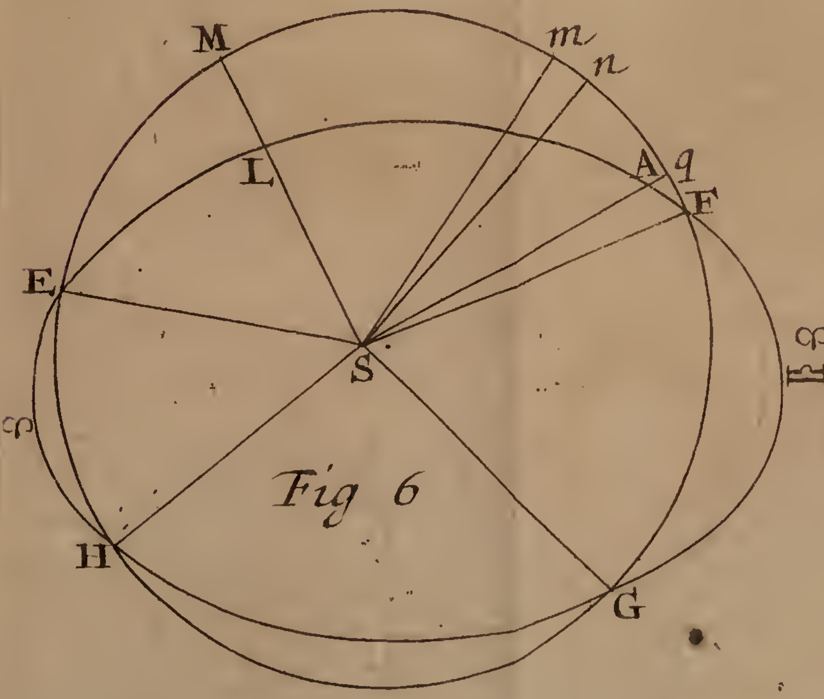


Fig 6

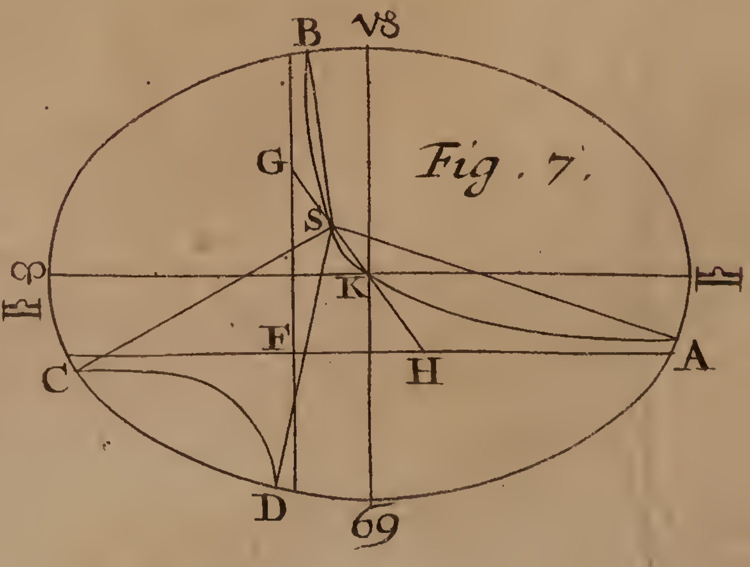


Fig. 7.

the Calculation ſuppoſes that the Motion of the Planet is in a Circle, and that thro' the whole Period it is uniform, which is not true.

A more accurate Method of finding the ſame.

THE following Method for finding the Periodical Times is more accurate. Obſerve a Planet twice ſucceſſively in the ſame Node; that is, let there be two Obſervations, when the Planet about the ſame part of its Orbit has no Latitude; which can only happen when the Planet has really no Latitude, and is placed in its Node: The Time between the two Obſervations will be equal to the Periodical Time of the Planet. For becauſe all the Planets move in Orbits whoſe Planes are different from the Plane of the Ecliptick, and the Sun is in the common *Focus* of all the Orbits, theſe Planes will all cut the Eclipτick in Lines which paſs thro' the Sun, and in the Interſections of theſe Lines with the Eclipτick are the Nodes; and the Planet in the whole time of its Period can never be obſerved but once in one and the ſame Node. Now the Nodes are either at reſt, or they have a very ſlow Motion, ſo that for the ſpace of one Period they may be eſteemed as at reſt. And therefore if we know the time between two arrivals of a Planet at the ſame Node immediately following each other, we ſhall likewiſe know the time of a Planet's Period.

BY the very ſame Obſervations, if we have the Theory of the Earth's Motion, we can find the Poſition of the Line of the Nodes or the points of the Eclipτick, in which that Line does interſect it. Let ATB be the Orbit of the Earth, CND the Orbit of the Planet, NS*n* the Line of the Nodes; and in the firſt Obſervation ſuppoſe the Earth in T, and the Planet to be obſerved in N: And becauſe the place of the Planet ſeen from the Earth is known by Obſervation, and the apparent place of the Sun, at the Time, is known by the Theory of the Earth's Motion; we have the Arch of the Eclipτick between the two places, or the meaſure of the Angle NTS. In the

Table XXV. Fig. 1.

the ſecond Obſervation let the Earth be in t, and the Planet in the ſame Node N, and we ſhall have by the ſame way the Angle NtS. In the right-lin'd Triangle TSt we have the ſides TS, tS, and the Angle TSt, which is known by the Theory of the Earth; therefore by *Trigonometry* we can find the Angles STt and StT, as likewiſe the ſide tT: Therefore from the known Angle STt take away the known Angle STN, and we ſhall have the Angle NTt. To the known Angle ntS add the Angle StT, which was found out, and we have the Angle NtT. Then in the Triangle NtT we have all the Angles and the ſide tT; conſequently we ſhall have the ſide NT, the diſtance of the Planet from the Earth at the firſt Obſervation. Laſtly, in the Triangle NTS we have the ſides NT and TS, and the Angle NTS which was known by Obſervation; conſequently we ſhall find the ſide NS the diſtance of the Planet from the Sun when he is in the Node, and the Angle TSN, which ſhews the Poſition of the Line of the Nodes; for that point of the Ecliptick which the Earth is in, ſeen from the Sun at the time of the Obſervation, is known; and the Angle TSN is likewiſe known: Therefore we have the point of the Ecliptick N, in which the Node is placed ſeen from the Sun; and the point n oppoſite to it will be the place of the other Node. And therefore the Poſition of the Nodes is found.

How to find the Poſition of the Nodes.

To find the Inclination of the Planet's Orb to the Ecliptick.

THE Places of the *Nodes* being once determined, we ſhall eaſily find the Inclination of the Plane of the Planets Orbit to the Ecliptick: For having the Places of the *Nodes*, we can find the Time when the Earth ſeen from the Sun is in one of them. At the ſame Time obſerve the *Geocentrick* Latitude of the Planet, and his diſtance from the oppoſite *Node*: Then the *Geocentrick* Latitude of the Planet is equal to the *Heliocentrick* Latitude it will have, when ſeen from the Sun at the ſame diſtance from the *Node*; that is, make the Angle nSp equal to the Angle nNP, and the

Plate XXV. Fig. 2.

Lati-

Lecture XXIV.

Latitude of the Planet at p obſerved from S, will be equal to its Latitude at P obſerved from N. For let CPD be the Orbit of the Planet, NSn the Line of the *Nodes*, BNT a Portion of the Orbit of the Earth, in which ſuppoſe the Earth to be at N in the Line of the *Nodes*, and the Planet in its Orbit to be at P; and then the Sun, Earth and Planet will be all in the Plane of the Planet's Orbit. From the Point P on the Ecliptick's Plane let fall the Perpendicular PE, and in the Plane of the Ecliptick draw the Line NE; then the Plane of the Triangle NPE will be Perpendicular to the Ecliptick, and the Angle PNE will be the viſible Latitude of the Planet ſeen from the Earth. Through S draw Spf parallel to NP, and pe parallel to PE; and the Plane through Sp and pe will be parallel to the Plane NPE, and conſequently perpendicular to the Plane of the Ecliptick; and therefore Se the common Section of the Ecliptick with this Plane will be parallel to NE. And becauſe NP and NE are parallel to Sp and Se, the Angle pSe the *Heliocentrick* Latitude, will be equal to the Angle PNE the Latitude of the Planet obſerved from the Earth in the *Node* N.

LET nf be a Portion of the Planet's Orbit extended to the Heavens, nh a Portion of the Ecliptick, fh a Circle of Latitude paſſing through the *Heliocentrick* place of the Planet. In the Right Angled Spherical Triangle nfh, having nh the diſtance of the Planet from the *Node*, equal to what was obſerved when the Earth was at N, and the Latitude fh equal alſo to what was obſerved at N, we can find from thence the Angle hnf the Inclination of the Plane of the Orbit to the Ecliptick, which was to be found out.

HAVING once found out this Inclination, by Obſervation we can find out the *Heliocentrick* place of the Planet, and his diſtance from the Sun, when ever he comes in oppoſition to the Sun.

How to find the Heliocentrick *place and diſtance from the Sun when the Planet is in oppoſition to the Sun.*

Plate XXV. Fig. 3.

LET ATB be the Orbit of the Earth, DPE the Orbit of the Planet: Suppoſe the Planet in P, and the Earth in T, and NS*n* the Line of *Nodes*, in which the Sun is in S. The Planet being in oppoſition to the Sun, its place reduced to the Ecliptick, will be in the Line ST, which paſſes through the Earth. Obſerve the Angle PTE the Planet's *Geocentrick* Latitude, and we have the Angle PST his *Heliocentrick* Latitude, becauſe we have the Planet's diſtance from the *Node.* Likewiſe by the Theory of the Earth's Motion, we have ST its diſtance from the Sun. And therefore in the Triangle PST, having all the Angles and one Side ST, we ſhall find SP the diſtance of the Planet from the Sun; and the Angle PS*n* the diſtance of the Planet from the *Node*, is found by the *Heliocentrick* Latitude, by which means we have the place of the Planet in his own Orbit. In the ſame manner if we have any other two Obſervations of the ſame Planet, in a Poſition or Aſpect oppoſite to the Sun, we ſhall have the Poſition and Magnitude of three Lines, through whoſe Extremities the Planet's Orb paſſes, and the Sun is in one of the *Foci* of the Orbit. And therefore to determine this Orbit, its Form and Poſition, we muſt deſcribe an Ellipſe whoſe *Focus* is given, and which will paſs through three given Points. The *Geometers* ſhew the Method of conſtructing this Problem, and we will likewiſe give the Solution of it hereafter.

To find the Heliocentrick *place and diſtance when the Planet is in any other Aſpect.*

Plate XXV. Fig. 4.

THOUGH a Planet were not in an Acronychal Poſition, but in any other Aſpect beſides an Oppoſition to the Sun, yet by one Obſervation its diſtance from the Sun and *Heliocentrick* place may be found. Suppoſe PAE the Orbit of the Planet, TGH the Orbit of the Earth. Let the Earth be in T, and the Planet in P, and the Sun in S in the Line of the *Nodes* NS. From P let fall the Perpendicular PB on the Plane of the Ecliptick: Draw BT, and produce it till it meets with the Line of the *Nodes* in N, and the Plane of the Triangle NPB will be perpendicular to the Plane of the Ecliptick. Let the Line CT be alſo perpendicular to it, and meet with the Plane of the Planet's Orb in C. From T upon the Line S N let fall the Perpendicular T D; joyn the points D and C, and the Angle T D C will be the Inclination of the Planet's Orbit to the Ecliptick, which Angle is therefore given. Obſerve the Angle *B* T P the Planet's *Geocentrick* Latitude, and the Angle B T **S** its Elongation from the Sun according to the Ecliptick. In the Triangle N T **S**, from the Theory of the Earth we have the ſide S T the diſtance of the Earth from the Sun, and the Angle T S N, which is known by the place of the Earth and *Node* in the Ecliptick, as alſo the Angle S T N the Complement of the Angle S T B to two Right Angles: hence we ſhall have NT. In the Right Angled Triangle T S D, having T S and the Angle T **S** D, we ſhall find T D; and therefore in the Right Angled Triangle TDC, having T D and the Angle T D C the Inclination of the Orbit to the Ecliptick, we ſhall find the ſide T C. In the Right-Angled Triangle T C N we have T C and N T, and therefore we can find the Angle T N C. And again, in the Triangle N T P, we have all the Angles; for the Angle N T P is the Latitude of the Planet found by obſervation, or its complement to two Right-Angles, and the Angle P N T juſt now found, as alſo the ſide N T, wherefore we ſhall find the ſide T P. In the Triangle PTB rectangular at B, we have the ſide T P, and the Angle P T B, which is the Latitude obſerved; wherefore we ſhall have the ſides B T and B P. And in the Triangle TSB, having T B and T S, and the Angle B T S, we ſhall have the ſide S B, which is called the *Curtate diſtance* of the Planet from the Sun, as alſo the Angle T S B, and conſequently the *Heliocentrick* place of the Planet reduced to the Ecliptick. Laſtly, in the Triangle PBS, we have the ſides PB, BS, and by them we ſhall have S P the diſtance of the Planet from the Sun, and the Angle P S B the *Heliocentrick* Latitude of the Planet. But having the *Heliocentrick*

centrick Latitude and the Inclination of the Planetary Orbit to the Ecliptick, we can find the Planet's diſtance from the *Node*, and conſequently his diſtance from the *Node* in his proper Orbit, and his Centrick place ſeen from the Sun. If by this Method we find out two other *Heliocentrick* places of the Planet and the diſtances from the Sun, having likewiſe the *Focus* of the Orbit which is the Center of the Sun, we may deſcribe an Ellipſe which ſhall paſs through the given points, and be the Orbit of the Planet.

Dr. Halleys *Method of determining the* Heliocentrick *place and diſtance from the Sun.* Plate XXV. Fig. 5.

THE moſt Ingenious Dr. *Halley* contrived another Method for finding out the Centrical places of the Planet, and its diſtances from the Sun, which ſuppoſes only that the Periodical time of the Planet is known. Let K L B be the Orbit of the Earth, S the Sun, P the Planet, or rather the point in the Plane of the Ecliptick on which the Perpendicular let fall from the Planet meets that Plane. And firſt when the Earth is in K, obſerve the *Geocentrick* Longitude of the Planet, and having the Theory of the Earth, we have the Apparent Longitude of the Sun; wherefore we have the Angle P K S. The Planet after it has compleated an intire Revolution, does again return to the ſame point P, at which time ſuppoſe the Earth in L, and there again let the Planet be obſerved, and find the Angle P L S, the Elongation of the Planet from the Sun. Having the times of the Obſervations, we have the places of the Earth in the Ecliptick, or the points K and L, and conſequently the Angle L S K, and the ſides L S and S K; wherefore we ſhall have the Angles S K L and S L K, and the ſide L K. From the known Angles S K P and S L P, take away the known Angles S K L and S L K, and we ſhall have the Angles P K L and P L K known; therefore in the Triangle P L K, having all the three Angles, and the ſide L K, we ſhall find the ſide P L; And in the Triangle P L S, having the ſides P L and L S and the intercepted Angle P L S, we ſhall have the Angle LSP, which determines the *Heliocentrick* place, and its diſtance from the *Node* according to the Ecliptick, as alſo the ſide SP. But as the Tangent of the *Geocentrick* Latitude is to the Tangent of the *Heliocentrick*, ſo is the *Curtate diſtance* of the Planet from the Sun, to its *Curtate diſtance* from the Earth. But by Obſervation we have the Planet's *Geocentrick* Latitude, wherefore its *Heliocentrick* Latitude will alſo be found. By which and the *Curtate diſtance* of the Planet from the Sun, we can find out the true diſtance which was wanted. If by this means we acquire three *Heliocentrick* places of the Planet, and the correſpondent diſtances from the Sun, we ſhall have the Form of the Orbit, and the Poſition of the *Apſides*, by deſcribing an Ellipſe which ſhall paſs through three given points. This *Ellipſis* is determined by the following Method.

To deſcribe a Planet's Orbit or to find its Poſition and Eccentricity Plate XXV. Fig. 6.

LET SD, SC and SB, be three Lines given in Magnitude and Poſition. Draw DC and BC and produce them, ſo that DF may be to CF as DS is to CS; and alſo CE to BE, as CS is to BS. Joyn FE, on which from S let fall the perpendicular SG, which will give the Poſition of the Axis. Draw the Lines DK, C*i* and BH; and cut SG in A, and produce it, ſo that GA may be to SA, as KD is to SD, and alſo G*a* be to S*a* in the ſame proportion; and make *sa* equal to SA. And the points A and *a* are the *Vertices* or *Apſides* of the Orbit, whoſe *Foci* are S and *s*, and greater Axis A*a*; and if with theſe *Apſides* and *Foci* we deſcribe an Ellipſe, it will be of the ſame Form with the Orbit of the Planet. For becauſe SD is to CS as FD is to FC, and ſo DK is to C*i*; by change of proportion, DS is to DK as CS is to C*i*, and ſo is SB to BH. But as DS is to DK, ſo by conſtruction is SA to GA, and S*a* to G*a*; therefore as SA : GA :: S*a* — *sa* or S*s* : *a*G — AG, or A*a*. And therefore we have SD : DK :: SC : C*i* :: SB : BH :: S*s* : A*a*. But this is the Property of an Ellipſe whoſe *Focus* is S, and greater Axis A *a*, as is demonſtrated by the Writers of Conicks, and particularly by Mr. *Milnes* in his Treatiſe of *Conick Sections*, Part IV. *Prop.* 9. It is evident therefore that the Ellipſe deſcribed with the *Foci* S, *s* and Axis A *a* will paſs thro' the points B C and D.

BECAUSE in *Aſtronomy* a Calculation is always preferable and more uſeful than the neateſt Conſtruction, the Form and Poſition of the Ellipſe is in this manner found out by Computation. In the Triangle D S C having the ſides D S and C S and the Angle D S C, we can find out the ſide D C with the Angles S C D and S D C; and in the ſame manner we can find in the Triangle B S C the ſide B C and the Angles S B C and S C B: And becauſe we have the *Ratio* of D F to C F and we have D C, we ſhall alſo have C F. In like manner, becauſe we have the *Ratio* of C E to B E and we have B C, we ſhall have C E and B E. But we have the Angle B C D equal to the Sum of two known Angles, and therefore we have the Angle F C E its Complement to two Right-Angles. In the Triangle F C E we have the ſides F C and C E, and the Angle F C E, wherefore we can find the Angle F E C, and its Complement to a Right the Angle *i* C E, to which adding the known Angle S C B, we have the whole Angle S C *i*: And becauſe S *a* and C *i* are parallel, the Angle C S *a* is equal to the Angle S C *i*: Having therefore the Angle C S *a* we have the Poſition of the Axis. In the Right-angled Triangle E C *i*, having E C and the Angle E, we can find C *i*; and therefore we can find the proportion of C S to C *i*. In the Triangle C S L, Right-angled at L, we have the Angle C S L the Complement of the Angle C S *a* to two Right-Angles, and the ſide C S: Therefore we ſhall have S L, to which adding L G equal to C *i*, we have the whole S G: And becauſe C S and C *i* are known, their proportion will be known:

As CS is to Ci, ſo let SA be to AG, and ſo let Sa be to aG, and ſo let Ss be to Aa, and we have the *Apſides* of the Ellipſe A and a, and its *Foci* S and s, which were to be found.

How to find a Planet's Mean Anomaly.

WE ſhewed above, how by an Obſervation to find the *Heliocentrick* place of a Planet, and we have now ſhewed how to determine the Poſition of the *Aphelion*; by which means we can find the diſtance of a Planet from the *Aphelion*, at the time of the Obſervation; this diſtance from the *Aphelion* is called the *true* or *Co-equated* Anomaly of the Planet. But having the Eccentricity of the Orbit, and the Periodical Time, we ſhewed before how to find the Planet's mean Anomaly, in the *Lecture* in which we gave the Solution of *Kepler*'s Problem; therefore at the time of the Obſervation we ſhall have the Mean Anomaly of the Planet, or the place he would have in his Orbit, did he conſtantly proceed with the ſame Angular Motion round the Sun. This being once obtained we have the Planet's Mean Motion for any other time. For ſay, as the Periodical Time of the Planet is to the Time between the Obſervation and the Moment of Time for which the Mean place is deſired, ſo is 360 Degrees or a whole Circle to a fourth. This Arch, if the Time preceded the Obſervation, being ſubſtracted from the place before found, or added to it, if it comes after the Obſervation, will give the Mean place of the Planet for the Time propoſed.

The Radix or Epocha.

FOR the more eaſily finding the Mean place of a Planet, for any Moment of Time, it will be eaſieſt to take out its Motion from the *Aſtronomical* Tables, in which is ſet down the Planet's Mean place or Mean Anomaly, in the beginning of any remarkable Æra; ſuch as is from the Birth of our Lord, the Æra of *Nabonaſſer*, of the Creation, the building of *Rome*, or the firſt Year of the *Julian* Period: the places of the Planets at theſe inſtants of Time, are found by the preceding Methods, and are computed according to the *Meridian* of *Equal Time*, and not for the *Apparent Time*. The place for that Time is called the *Epocha* or *Radix*, that is, the Root; from which, as from an immoveable Foundation, all the Motions are Calculated.

How to Compute the Mean Anomaly.

IF the Times be Numbred by the Years from the Birth of *Chriſt*, or from the beginning of the *Julian* Period. It will be moſt convenient that the Year take its beginning from that Mid-day which preceded the firſt of *January*, ſo that at the Mid-day of the firſt of *January* there is one Day compleatly finiſhed. Say, as the Periodical Time is to a common Year of 365 Days, ſo is a whole Circle or 360 Degrees to a fourth, which will be the Mean Motion of the Planet for one Year. In like manner ſay, as the Periodical Time is to a Day, ſo a whole Circle is to a fourth; and we ſhall have the Mean Anomaly pertaining to one Day. And by working with the like Proportion we ſhall have the Mean Anomaly for an Hour, and for every Minute and Second. And if we add the Motion for one Year continually to itſelf, we ſhall have the Motion in two, three and four Years: But becauſe every fourth Year is *Biſſextile*, and conſiſts of 366 Days, to the Motion of the fourth Year we muſt add the Motion of one Day; then by conſtantly adding the Motion of one Year, we ſhall have the Motion of five, ſix and ſeven Years. But the Motion of the Eighth Year is to be increaſed by the Motion of one Day, or rather the Motion of four Years is to be doubled, to have the Motion of Eight Years; becauſe that Year is *Biſſextile*. From theſe Motions ſo collected by Addition, we muſt always reject the whole Circles or 360 Degrees, for after a Planet has compleated its Circle, it returns to the ſame place. By this Method we have the Mean place of the Planets to 20 Years; and if the Motion of 20 Years be conſtantly added to itſelf, we ſhall have the Mean place for 40, 60, 80 and 100 Years; and to each of them add the Motion of 10 Years, and we have the Motions and places for 30, 50, 70 and 90 Years. And by the continual addition of the Motions of 100 Years, rejecting always whole Circles, we ſhall have the Motions of 200, 300, 400, 500, *&c.* Years, even to 1000: And proceeding in the ſame way, we ſhall have the Motion of 2000, 3000, 4000 and 5000 Years, and ſo as far as you will.

THESE Motions being in this way computed, are to be diſpoſed in Tables, which are called Tables of the Mean Motion, or Mean Anomaly, when they are numbered from the *Aphelion*, and they are found in all the *Aſtronomical* Tables for each Planet. But if the Mean Motions are computed from the Equinoctial points, inſtead of the Periodical Time, you muſt take the time the Planet revolves in the *Zodiack*, which is ſomewhat leſs than the Periodical Time, becauſe of the Præceſſion of the Equinocties, by which the Interſection of thoſe Points meet the Planet. If the *Aphelia* of the Planet be ſuppoſed to move, this Motion muſt be conſidered, and the Motion of the Equinocties and of the *Aphelia* (which for ought we know are equal, but in the Moon) are likewiſe to be computed and diſpoſed in Tables for Years, Tens, Hundreds, and Thouſands of Years, as the other Mean Motions are; that for any Time we may have the places and diſtances of the *Aphelia* from the Equinocties.

THE *Aſtronomers* have ſome other Tables which give the true Anomalie anſwering to every Degree of Mean Anomaly, which are computed by ſome of the Methods delivered above in the former *Lectures*. If Minutes and Seconds are added to the Mean Motions, we muſt take the difference of the True Anomalies, which are one Degree diſtant from each other, and by proportioning, we muſt add that part which is to be added to the Tabular Anomaly which is next leaſt, or is to be ſubſtracted from it, if it be next greateſt.

FOR the Motions of the Sun and Moon, they commonly compute the Equations or *Proſthaphæreſis*, which are the differences between the true and mean Anomaly; and they, either ſubſtracted or added to the mean Anomaly, as the Planet is in the firſt or ſecond Semicircle of Anomaly, give the True.

The Argument of Latitude.

HAVING the Places of the *Aphelion* and *Nodes*, we have their diſtance from each other: And therefore having the True Anomaly of the Planet, we have its diſtance from the *Node*, which is called the *Argument of Latitude*, by which, and an eaſy *Trigonometrical* Calculation, we can find the Centrical Latitude of the Planet, and its *Curtate diſtance* from the Sun, which is the diſtance from the Sun to that point, where a perpendicular let fall from the Planet meets with the Ecliptick. And thus we have ſhewed how to find the Centrical place and Latitude of the Planet, and its *Curtate diſtance* from the Sun. After theſe are found, we ſhall likewiſe be able to find his *Geocentrick* place, or where he will be ſeen from the Earth, in the following Method.

The Curtate diſtance of a Planet.

FIND firſt the Planet's *Heliocentrick* place and *Curtate diſtance* from the Sun, as alſo the Earth's place and diſtance from the ſame. Let TCF be the Orbit of the Earth, in which the Earth is in T; APE the Orbit of the Planet, and its place P, the Sun S, *n* S N the Line of *Nodes*. From the place of the Planet let fall on the Plane of the Ecliptick the right Line PB; draw SB and produce it till it meet with the Ecliptick in the Planet's place reduced to the Ecliptick, which place is found by the Arch PN and the Inclination of the Orbit to the Plane of the Ecliptick, which are known: But we have the place of the Earth ſeen from the Sun; and therefore we have the diſtance between them, or the Angle TSB, which is called *the Angle of Commutation.* Then in the Triangle STB, we have ST the diſtance of the Earth from the Sun, and SB the *Curtate diſtance* of the Planet; wherefore we ſhall find the Angle STB the Elongation of the Planet from the Sun, or the Arch of the Ecliptick intercepted between the Sun's place and the

The Angle of Commutation.

Planet's place reduced to the Eccliptick; as alſo T B, the curtate diſtance of the Planet from the Earth. But the place of the Sun is given, for it is oppoſite to the place of the Earth ſeen from the Sun: Wherefore alſo we ſhall have the place of the Planet in the Eccliptick as it is ſeen from the Earth. Moreover, in the two Triangles P S B and T P B that are rectangular at B, the Tangent of the Angle P S B is to the Tangent of the Angle P T B, as T B is to S B: But as T B is to S B, ſo is the Sine of T S B the Sine of the Commutation, to the Sine of the Elongation S T B. Wherefore ſay as the Sine of the Commutation is to the Sine of the Elongation, ſo is the Tangent of the Heliocentrick Latitude to the Tangent of the Geocentrick Latitude, which was to be found. And by theſe means the *Aſtronomers* are able to find, for any inſtant of Time, the Geocentrick place and Latitude of any Planet.

How to compute the Planet's Geocentrick place.

Plate XXVI. Fig. 1.

COMPARING the diſtances of the Planets from the Sun with the Times of the Periods round him, we find that they all obſerve a wonderful regular and elegant Harmony and Law, *viz.*

The Harmony between the Periods and Diſtances of the Planets.

THE *ſquares of the Periodical Times are in all of them proportional to the Cubes of their mean diſtances from the Sun.* Now their Periods and mean diſtances are theſe, which we here give in the following Table.

	The Periods.				*Mean Diſtances.*
	D.	h.	′	″	
♄	10759	6	36	26	953800
♃	4332	12	20	35	520110
♂	686	23	27	30	152369
☉	365	6	9	30	100000
♀	224	16	49	24	72333
☿	87	23	15	53	38710

THE illuſtrious Mathematician Mr. *Hugens*, has determined very nicely the Diameters of the

Planets, by comparing them with that of the Sun, in his *Saturnian Syſtem*, which he did by the following Method.

COPERNICUS by his New and divinely invented Syſtem, has ſhewed us how to find out the diſtance of each Planet from the Sun, in proportion to the Earth's diſtance from the ſame: But their apparent Diameters, and how much ſome are bigger than others, has been diſcovered by the help of the Teleſcope. For by comparing the proportions of their diſtances and apparent Magnitudes, the proportion of their true bigneſs to that of the Sun will eaſily be found, by the Principles we have layed down in our firſt *Lecture*.

The Diameters and Magnitudes of the Planets eſtimated.

AS for *Saturn*, the Diameter of his Ring, when he is neareſt to us, ſubtends an Angle of 68 Seconds: And becauſe this leaſt diſtance of *Saturn* is near eight times the mean diſtance of the Sun from us. It follows, that if *Saturn* were as near us as the Sun is, the Diameter of the Ring would appear eight times bigger than now it does, that is, it would be 9′. 4″. But the Diameter of the Sun in his mean diſtance is 30′. 30″. Therefore the proportion of the Diameter of the Ring to the Diameter of the Sun, is that of 9′. 4″. to 30′. 30″; which is near the proportion of 11 to 37. But the Diameter of *Saturn*'s body is to the Diameter of the Ring as 4 to 9; that is nearly as 5 to 11: And therefore it is to the Diameter of the Sun as 5 to 37.

JUPITER's Diameter, when he is next to us, is 64 Seconds; and then his diſtance is to the mean diſtance of the Sun as 26 to 5; ſay as 5 is to 26, ſo is 64 Seconds to a fourth, which will be 5′. 35″; which is the bigneſs of the Angle that *Jupiter's* Diameter would ſubtend, were he as near as the Sun is: But the Sun is ſeen under an Angle of 30′. 30″. Therefore the proportion of *Jupiter's* Diameter to that of the Sun is as 5′. 35″ to 30′. 30″; that is a little more than 1 to $5\frac{1}{2}$.

Plate XXV

front. p. 342

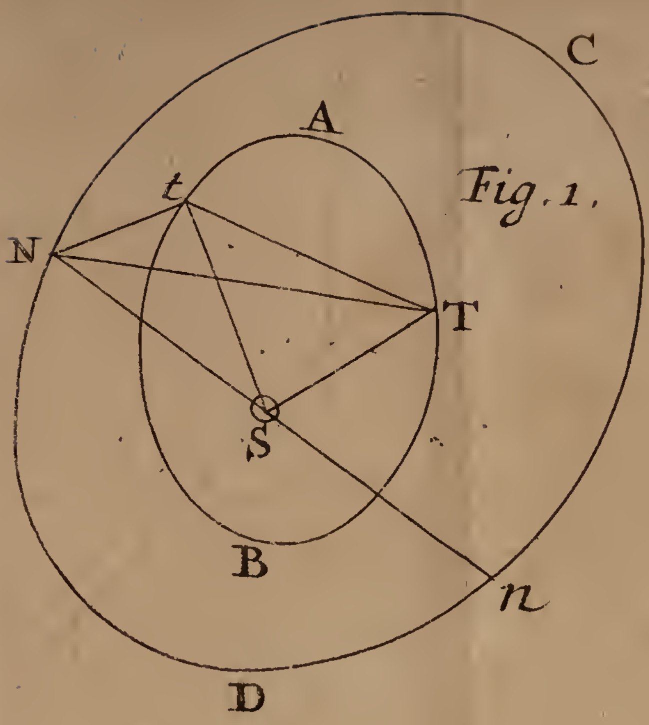


Fig. 1.

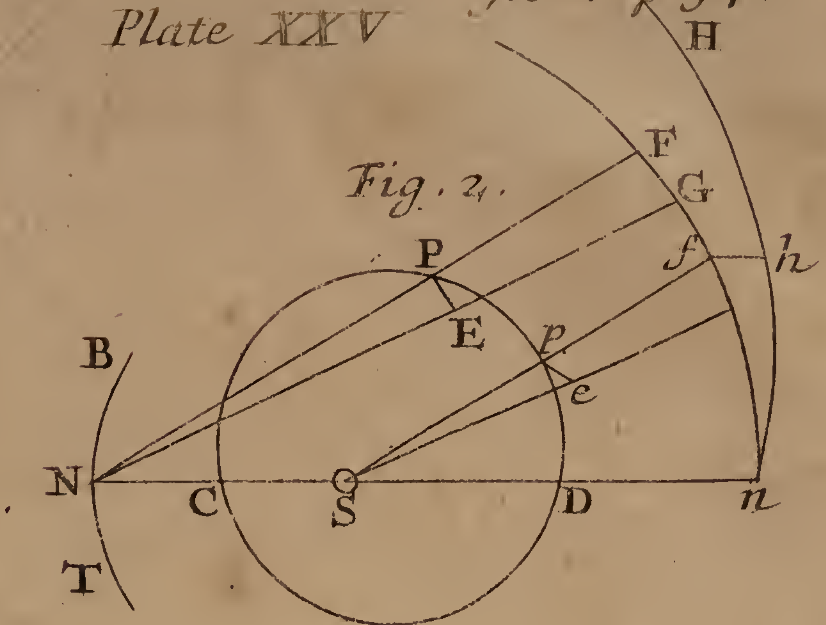


Fig. 2.

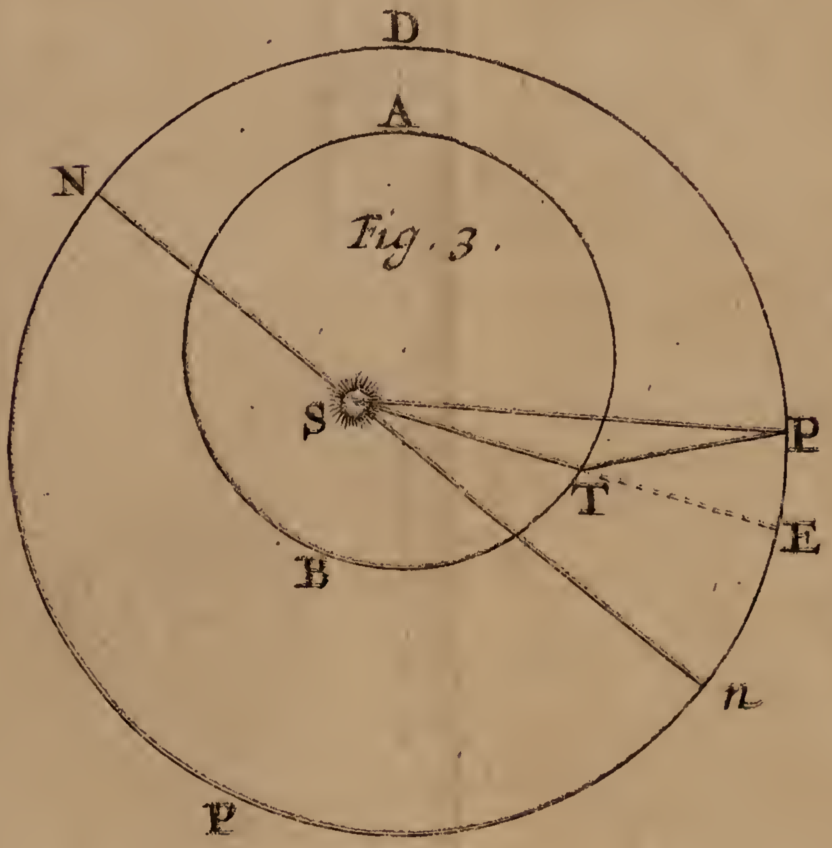


Fig. 3.

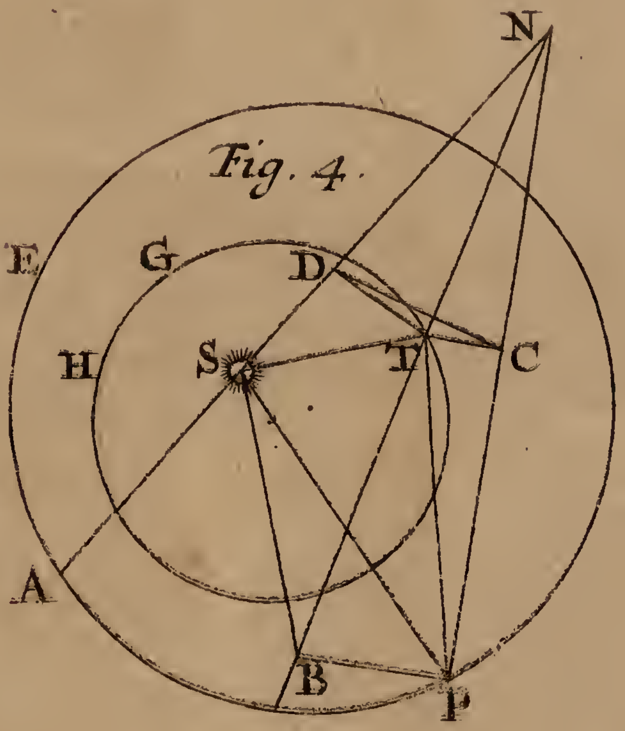


Fig. 4.

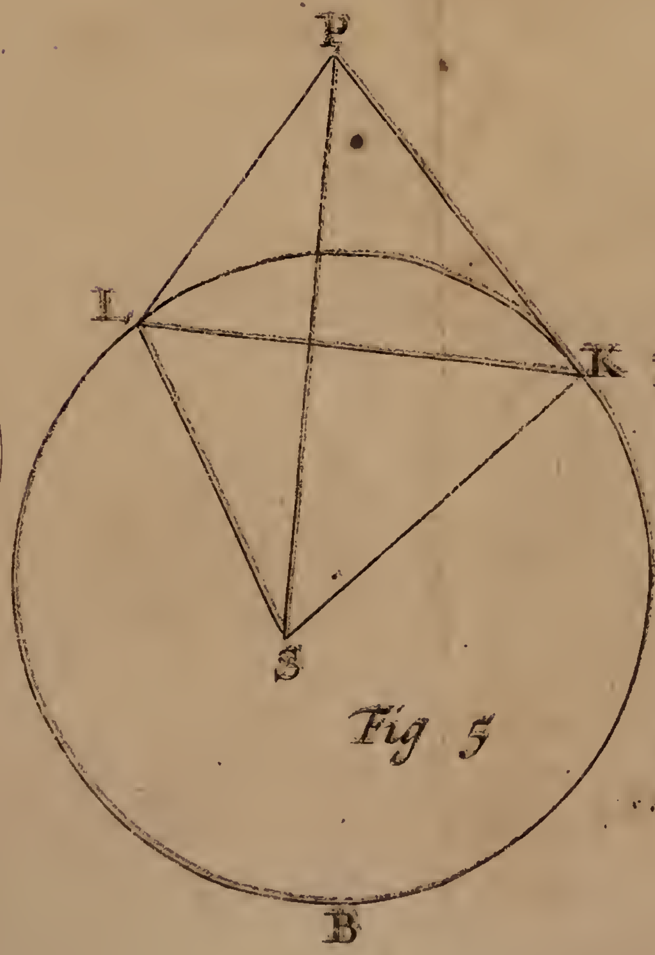


Fig 5

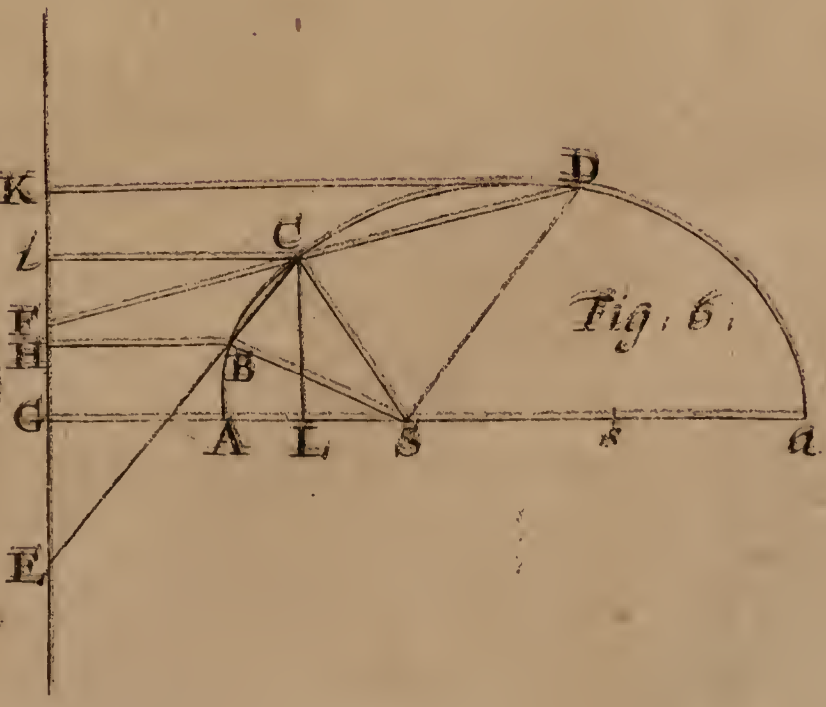


Fig. 6.

VENUS, when ſhe is neareſt the Earth, ſubtends an Angle of 85 Seconds; and then her *Perigæon* diſtance is to the mean diſtance of the Sun nearly, as 21 is to 82: And therefore if *Venus* were removed to the diſtance of the Sun, her Diameter would be only 21″. 46‴: And therefore we know that the Diameter of *Venus* is to that of the Sun as 21″. 46‴ to 30½′; that is as 1 to 84.

BUT the Diameter of *Mars*, when neareſt to the *Earth*, is not greater than 30″: And therefore ſince the leaſt diſtance of *Mars* is to the Sun's mean diſtance as 15 to 41; the proportion of *Mars*'s Diameter will be to the Sun's Diameter as 1 is to 166: Therefore *Mars* is but half the bigneſs of *Venus* in its Diameter. *Hevelius* by Obſervations found that *Mercury*'s Diameter was to that of the Sun as 1 is to 290.

THE Magnitude of the Earth in compariſon of that of the Sun is variouſly eſtimated by the *Aſtronomers*: They who ſuppoſe the horizontal Parallax of the Sun to be 15 Seconds, muſt make the diſtance of the Sun from us to be but 13750 Semidiameters of the Earth; and the Diameter of the Earth will be to the Diameter of the Sun as 1 to 61: But we have a probable Argument which proves the Diſproportion or Inequality greater. For becauſe the Diameter of the Moon is ſomewhat more than a fourth part of the Diameter of the Earth; if the Parallax of the Sun were 15 Seconds, then the body of the Moon would be greater than that of *Mercury*; but it ſeems incongruous, that a ſecondary Planet ſhould be greater than a primary Planet. Let us ſuppoſe therefore that the Semidiameter of the Earth ſeen from the Sun be 11 Seconds, as it was lately collected from the Parallax of *Mars*, obſerved by Dr. *Halley* and Mr. *Pound*: And then the Earth's diſtance will be nearly 20000 Semidiameters of the Earth, and the Moon will be leſs than *Mercury*. And the Proportion of the Diameter of the Earth to the

Sun will be that of 1 to 83; to which Proportion we may give our Aſſent, 'till by an Obſervation of *Venus* in the Sun's Body, which will happen in 1761, we may be made more certain of the Sun's Parallax. Therefore the Diameter of the Sun is to the Planet's Diameters, nearly in the proportions repreſented in the following Table.

The Diameter of the Sun is to the Diameter of	*Saturn*	as 1000 is to	137
	Jupiter		181
	Mars		6
	the Earth		12
	Venus		12
	Mercury		4

AND becauſe Spheres are to one another as the Cubes of their Diameters,

The Sun will be to	*Saturn*	as 1000000000 is to	2571353
	Jupiter		5929741
	Mars		216
	the Earth		1728
	Venus		1728
	Mercury		64

HENCE it follows, that the Sun is a hundred and ſixteen times bigger than all the Planets put together. *Saturn* is 400 times leſs than the Sun: But for quantity of Matter it is 2400 times leſs than the Matter of the Sun. *Jupiter*, the biggeſt of all the Planets, is 160 times leſs than the Sun; and his Matter that compoſes his Body is 1033 times leſs than the Matter of the Sun. But our Earth, if it be compared with the Sun, is but of a very ſmall Magnitude, and not bigger than a Phyſical Point; for it is 500000 times leſs than it. Beſides, comparing the Planets with one another, we find that *Jupiter* is bigger than all the reſt of the Planets put together; and that he is above 2000 times bigger than the Earth; but *Venus* is of the ſame bigneſs with the Earth. And yet there are two of the ſix Planets, *viz. Mercury* and *Mars* leſs than the Earth.

LECTURE XXVII.

Of the Stations of the Planets.

IF the Earth were at reſt, and the Planets alone turned round the Sun, an inferiour Planet would ſeem to be ſtationary, in that point of its Orbit, where a Line drawn from the Earth touched the Orbit; for when the Planet is near that point, if the Earth ſtood ſtill, it would directly approach the Earth, and would have no viſible Motion, or at leaſt its viſible Motion would be the leaſt of all. In like manner, if a ſuperiour Planet were at reſt, when it is viewed from the Earth, it would appear to ſtand in that part of its Orbit, where a Line drawn from the Planet touches the Earth's Orbit. But becauſe both the Earth and Planets move round the Sun, when an inferiour Planet is in the forementioned Tangent, then the Motion of the Earth will make the Planet appear to change its place, and the Planet will not be come to its apparent Station. And upon the ſame account, when the Earth is in the Line which touches its Orbit and paſſes to a Planet, the proper Motion of the ſuperior Planet will change its viſible place. And therefore it happens, that neither an inferior Planet ſeems to reſt, when it and the Earth are in a Line which touches its Orbit; nor is a ſuperior Planet ſtationary, when the Earth and it are in a Line touching the Orbit of the Earth.

An inferiour Planet is not ſtationary when it is ſeen in a right Line touching its Orbit.

Nor is a ſuperiour ſtationary when it is ſeen in a Line touching the Earth's Orbit.

BUT

When a Planet appears ſtationary.

BUT ſince all the Planets do ſometimes appear to move forward, and afterwards to return backwards; between the progreſſive Motion and the regreſſive, there will be ſome point, where it will appear to ſtand and continue in the ſame Situation in the Heavens. Now it ſeems to keep the ſame Station in the Heavens, when the Line that joins the Earth and Planet's Center is conſtantly directed to the ſame point in the Heavens; that is when it keeps parallel to itſelf: For all Right Lines drawn from whatever point of the Earth's Orbit parallel to one another, do all point to the ſame Star; becauſe the diſtance of theſe Lines is not ſenſible in compariſon of the great diſtance of the Fixed Stars.

THEREFORE to find out the points of Station, we muſt inquire the poſition of the Line, which joyning the Earth and Planet, keeps parallel to itſelf: For which purpoſe we muſt obſerve, that if the Centers of the Sun, Earth and Planet be joined by Right Lines, they will form a Triangle, whoſe two ſides drawn from the Sun are always equal to the diſtances of the Earth and Planet from the Sun; and the Baſe is a Right Line joining the Earth and Planet: And becauſe the ſides of this Triangle, in circular concentrick Orbits, do keep always the ſame Magnitude, the proportion of the Sines of the Angles at the Baſe will be conſtantly the ſame: for the Sines are as the oppoſite ſides.

Table XVI. Fig. 1.

LET the Circle B D G be the Orbit of the Planet, and A H K the Orbit of the Earth concentrical to it. And let us ſuppoſe the Earth in A, the Planet in B, and the Sun in the Center S. In the Triangle A S B, the Sines of the Angles A and B at the Baſe, are as the oppoſite ſides S B, S A.

LET us ſuppoſe then that in a ſmall Particle of Time, the Earth is moved thro' the ſmall Arch A C, and the Planet at the ſame time thro' the Arch of its Orbit B D; their angular

Motions at the Sun made in the ſame or equal Times, are reciprocally as their Periodical Times; for how much the greater is the Periodical Time, ſo much leſs is the Angle it deſcribes round the Sun in any given Time. Therefore the Angle A S C the angular Motion of the Earth, is to the Angle B S D the angular Motion of the Planet, as the Periodical Time of the Planet is to the Periodical Time of the Earth; that is the angular Motions in the ſame time are in a conſtant Proportion.

LET the Center of the Earth in C and of the Planet in D be joined by the Line C D, which is parallel to the former Line A B: And in that Caſe, as we have ſhewed, the Planet will appear ſtationary. Let S A cut C D in M, and S D produced cut A B in E: And becauſe A B and C D are parallel, by the 29*th* of *El.* I, the Angle S M D will be equal to the Angle A; but by the 32*d* of the firſt *El.* the Angle S M D is equal to the Angles C and M S C; wherefore the Angle C is equal to the Angle A, bating the Angle M S C or C S A. Likewiſe becauſe of the Parallels A B and C D, the Angle S D C is equal to the Angle S E A, which is equal to the Angles S B A and B S E; wherefore that Angle is equal to the Sum of the two Angles S B A and B S E. Therefore the momentanous Increaſe of the Angle S B A is equal to the angular Motion of the Planet at the Sun. And before it was ſhewed that the Decrement of the Angle A was equal to the Angle A S C, or to the angular Motion of the Earth; but theſe angular Motions are conſtantly in a given Proportion, which is reciprocal to their Periodical Times.

A Planet therefore appears ſtationary when the momentanous Change of the Angle at the Earth, is to the momentanous Change of the Angle at the Planet, as the Periodical Time of the Planet is to the Periodical Time of the Earth.

Table XVI. Fig. 2.

LET there be two Arches or Angles whoſe Sines are to one another in a conſtant Proportion.

tion. I ſay that their Coſines or the Sines of the Complements of theſe Arches, are in a proportion compounded of the direct Proportion of the Sines of theſe Arches, and a reciprocal proportion of the momentanous Changes of the Arches or Angles. For Example, Suppoſe the two Arches A M and C M, whoſe Sines are A B and C D, and their Coſines S B, S D. Let the Arches A M and C M decreaſe into E M and G M; ſo that the Sines E K, G L may be proportional to the former A B and C D. Let A E and C G be the Decrements of the Arches, which being infinitely ſmall may be taken for Right Lines. Draw F E and G H parallel to S M; the Triangles A F E and A S B are equiangular: For the Angles B and A F E are both right, and the Angle E A F is equal to the Angle A S B, the Angle S A B being the Complement of both to a Right-Angle. After the ſame way it may be proved that the Triangles C H G and C S D are equiangular. Therefore C G : C H :: C S : S D; And A F : A E :: S B : A S or C S: Wherefore multiplying the Antecedents together and the Conſequents together, we have the Proportion C G × A F : C H × A E :: C S × S B : S D × A S or C S × S D :: that is S B is to S D in a proportion compounded of A F to C H, and of C G to A E. But the *Ratio* of A F to C H is the ſame with the *Ratio* of the Sines A B and C D; and the *Ratio* of C G to A E is the *Ratio* of the momentary Decrements of the Arches C M and A M. Therefore S B the Co-ſine of the Arch A M, is to S D the Coſine of the Arch C M, in a proportion compounded of the direct proportion of the Sines of theſe Arches, and a reciprocal proportion of the inſtantaneous Decrements of the Arches, that is of C G to A E.

HENCE if the Centers of the Sun, of the Earth, and of a Planet that is ſtationary be joined with Lines, the Coſine of the Angle at the Earth will be to the Coſine of the Angle at the Planet, in a proportion compoſed of the Sines of the

the Angles A and B, and a reciprocal proportion of the momentary Decreaſe of thoſe Angles A and B. But the proportion of the Sines is the ſame with the proportion of the diſtances of the Earth and Planet from the Sun; and the *Ratio* of the momentary Decreaſe of the Angles A and B, is the proportion of the Periodical Times of the Planet and the Earth, as has been proved. Let the Periodical Times be called *t* and T; and then the Coſine of the Angle A will be to the Coſine of the Angle B, when the Planet is ſtationary, as T × S B is to *t* × S A; that is, the Coſine of the Angle at the Earth is to the Coſine of the Angle at the Planet in a proportion compounded of the Periodical Times directly, and a reciprocal proportion of the diſtances from the Sun. Hence the points of Stations are eaſily determined by the following Conſtruction.

Table XVII. Fig. 3.

LET A H be a portion of the Orbit of the Earth, G B K a portion of the Planet's Orbit, and let the Sun S be in the Center of both Orbits. Cut S A in E, ſo that S A may be to S E as the Periodical Time of the Earth is to the Periodical Time of the Planet. Upon the Diameter A E deſcribe a Semicircle cutting the Orb of the Planet in B, the Angle S A B will be the Elongation of the Planet from the Sun, when it appears ſtationary. Draw the Lines A B F, E B, and S F parallel to E B, and the Angle A B E, in a Semicircle, is a Right-Angle: And therefore A S F parallel to it muſt be right likewiſe. Moreover A S : A F : : Rad. Coſine of A; and alſo B F : S B : : Coſine S B F : Rad. Therefore multiplying the Antecedents together and the Conſequents together, we ſhall have A S × B F : A F × S B : : as the Coſine of S B F is to the Coſine of the Angle A. Therefore the *Ratio* of the Coſine of the Angle A to the Coſine of the Angle S B F, is compounded of the *Ratio* of A F to B F and of S B to A S. But the *Ratio* of A F to B F is equal to the *Ratio* of A S to S E, or of T to *t*. Therefore the *Ratio* of the Coſine of the Angle A to the Coſine of the Angle S B F, is compounded of the *Ratio* of T to *t*, and of S B to S A. But it was ſhewed that when the Coſines of the Angles had this proportion, then the Planet would be ſtationary. Therefore it is evident, that when the Planet is in B and the Earth at A, the Planet will appear to be ſtationary.

HENCE we ſee that when an inferior Planet is ſeen from the Earth to be ſtationary, the Earth alſo viewed from the inferior will likewiſe appear to be ſtationary, and will ſeem to remain in the ſame place. For the Earth is ſeen ſtationary, when the Line that joins the Centers of the Planet and Earth keeps parallel to itſelf; and ſo long as this Line keeps a Paralleliſm, it will always be directed to the ſame point in the Heavens.

BY the ſame Method we find the Poſitions of the other ſuperior Planets in reſpect of the Earth and Sun, when they are to be obſerved by us to be ſtationary, *viz.* by inquiring where the Earth, conſidered as an inferior Planet, will appear ſtationary, ſeen from a ſuperior Planet.

IF the Periodical Times were proportional to the diſtances from the Sun, the Points E and B would coincide with G, and the Planet would be ſtationary when the Angle A was nothing; that is when the inferior Planet was in Conjunction with the Sun: But if S E bore a greater proportion to S A than S G did to S A, the Circle A B E could cut the Planet's Orb in no point at all; and the Planet could no where be ſtationary, but would appear conſtantly to move directly forward: But neither of theſe Caſes obtain place in the Planets; for S E is always leſs than S G or S B, which I thus demonſtrate.

CALL the diſtance of the Earth from the Sun *p*, the diſtance of the Planet S G or S B call *q*, the Periodical Times T and *t*. And by the univerſal Law above explained and obſerved in all the Planets, we have $T^2 : t^2 :: p^3 : q^3$, and $T : t :: p^{\frac{3}{2}} : q^{\frac{3}{2}} :: p \times p^{\frac{1}{2}} : q \times q^{\frac{1}{2}}$; but as T is to t, ſo is SA : SE :: p : SE. Say therefore as $p \times p^{\frac{1}{2}} : q \times q^{\frac{1}{2}} :: p$ to $\frac{q \times q^{\frac{1}{2}}}{p^{\frac{1}{2}}}$; which which is therefore equal to SE: And becauſe p is greater than q; therefore $q \times p^{\frac{1}{2}}$ is greater than $q \times q^{\frac{1}{2}}$; and dividing all by $p^{\frac{1}{2}}$, we have q greater than $\frac{q \times q^{\frac{1}{2}}}{p^{\frac{1}{2}}}$ or than SE. And therefore ſince SB or SG is greater than SE, the Circle upon the Diameter AE will cut the Orbit of the Planet: And therefore we on the Earth, in ſome certain Poſitions, may ſee each of the Planets ſtationary.

IF you deſire to uſe a Calulation, the Angle at the Earth or the Elongation of the Planet from the Sun is defined in this manner. Let the Radius be z, and the Sine of the Angle at the Earth qx; the Sine of the Angle at the Planet will be px, ſuppoſing that p is to q in the proportion of the Earth and Planet's diſtances from the Sun: And becauſe the Sine of the Angle at the Earth is qx, its Coſine is $\sqrt{z^2 - q^2x^2}$; and the Coſine of the Angle at the Planet will be $\sqrt{z^2 - p^2x^2}$: And therefore $\sqrt{z^2 - q^2x^2} : \sqrt{z^2 - p^2x^2} :: T \times q : t \times p$: And ſquaring the Terms of the Analogy $z^2 - q^2x^2 : z^2 - p^2x^2 :: T^2 \times q^2 : t^2 \times p^2$; but $T^2 : t^2 :: p^3 : q^3$: Wherefore inſtead of T^2 and t^2 put p^3 and q^3, which are proportional to them, and we ſhall have $z^2 - q^2x^2 : z^2 - p^2x^2 :: p^3 \times q^2 : q^3 \times p^2 :: p : q$: And therefore we have the Equation $qz^2 - q^3x^2 = pz^2 - p^3x^2$, and $p^3x^2 - q^3x^2 = z^2 \times \overline{p - q}$; and $x = z \times \frac{\sqrt{p - q}}{\sqrt{p^3 - q^3}}$

and qx the Sine of the Angle at the Earth $= qz \times \frac{\sqrt{p-q}}{\sqrt{p^3-q^3}}$, which is equal to $\frac{qz}{\sqrt{p^2+pq+q^2}}$; therefore the ſquare of the Coſine of this Angle is $z^2 - \frac{q^2z^2}{p^2+pq+q^2} = \frac{z^2p^2+z^2pq}{p^2+pq+q^2}$; and therefore the Coſine is $z \times \frac{\sqrt{p^2+pq}}{\sqrt{p^2+pq+q^2}}$: The Coſine is therefore to the Sine as $z \times \frac{\sqrt{p^2+pq}}{\sqrt{p^2+pq+q^2}}$ to $\frac{qz}{\sqrt{p^2+pq+q^2}}$ as $\sqrt{p^2+pq}$ is to q. But as the Coſine is to the Sine, ſo is the Radius to the Tangent; therefore ſay as $\sqrt{p^2+pq}$ is to q, ſo z is to $\frac{zq}{\sqrt{p^2+pq}}$, which is the Tangent of the Angle at the Earth: And by this Analogy the Angle is eaſily found. For if half the Sum of the Logarithms of p and $p+q$ be ſubſtracted from the Logarithm of q, there will remain the Logarithmick Tangent of the Angle at the Earth. From this value of the Tangent we have the following Geometrical Conſtruction, which
Table XVI. Fig. 4. determines the Angle. Let H A Q be a portion of the Earth's Orbit, G B D the Orbit of the inferior Planet, and the Sun in S the common Center of the Orbits. Produce A S till it meets with the inferior Orbit in D; upon the Diameter A D deſcribe the Semicircle A C D, and at S erect upon A D the Perpendicular S C cutting the Semicircle in C; join A C, in which take A F = S D; and from F upon A S let fall the Perpendicular F E; in S C take S L = A E, and draw A L: Then S A L will be the Angle required; and B, where A L cuts the inferior Orbit,

will be the point of the Station: For the ſquare of S C is equal to the Rectangle A S D $= pq$, and A C ſquare $=$ A S ſquare $+$ S C ſquare $= p^2 + pq$: But A C : A F :: A S : A E :: A S : S L :: The Radius : Tangent of the Angle S A L, that is $\sqrt{p^2 + pq} : q :: z : \frac{zq}{\sqrt{p^2 + pq}}$, which is therefore the Tangent of the Angle required.

THESE Calculations and Conſtructions would ſufficiently determine the points of Station, if the Planets Orbits were concentrical Circles: But ſince they are Eccentrick and Ellipſes, both the Angles at the Sun and Planet will be different and changeable, according to the different places of the Planets in their Orbits, at the points of Station. And therefore becauſe in this Caſe, according to the infinite Varieties of poſition of the Earth and Planets in their Orbits, there will be likewiſe an infinite variety of Angles, they cannot be defined by any Algebraical Equation; neither can the *Problem* be univerſally conſtructed by any Algebraick Curve of any kind, altho' ſome Mathematicians have undertaken to do it. Yet if we have the poſition of a Planet in its proper Orbit, we may find the poſition of the Earth in its Orbit, from whence the Planet in that point will appear ſtationary.

FOR this is a determined *Problem*, and admits of two Anſwers, for the two Roots of the Equation that involves the nature of the *Problem.* The moſt induſtrious Dr. *Halley*, hath communicated to me the following Solution of this *Problem*; for the underſtanding of which we give the following *Lemma.*

WHATEVER the form of the Earth and Planet's Orbits may be; if from their places in the times of Station there be drawn Tangents to the Orbits, and produced 'till they meet; the portions of thoſe Tangents intercepted by their mutual concourſe, are proportional to the abſolute Velocities of the Earth and Planets.

Table XVI. Fig. 5.

LET FG and AH be two portions of the Orbits which the Earth and Planet deſcribe; AB and CD two infinitely ſmall portions of them, deſcribed in the ſame time, when the Planet is ſtationary: Draw the Lines CE and AE touching the Orbits and meeting in E. And becauſe the Planet is ſtationary, BD and AC will be parallel: And therefore by the 2*d Prop. El.* VI. CD : AB :: CE : AE. But CD and AB, ſince they are Portions of the Orbits deſcribed in the ſame time, are as the Velocities of the Earth and Planet: Therefore the Tangents CE and AE, are as the Velocities. This *Theorem* is Mr. *John Bernoulli*'s, and is Publiſhed in the *Berline* Acts, and flows immediately from the Paralleliſm of the Lines AC, BD: But Mr. *Bernoulli* has not given us from thence any Solution of the Problem. Dr. *Halley*'s Solution is this.

PROBLEM.

To find the Place of the Earth, from which a Planet ſeen in a given Point of its Orbit would appear Stationary.

SUPPOSE the Sun at S, ΠKLA the Orbit of the Earth, which we may here ſuppoſe to be Circular, πPα the Orbit of the Planet, P its given place. Draw VPQ touching the Orbit in P, and interſecting the Orbit of the Earth in V and Q, Biſect VQ in R, and on it erect the Perpendicular PB, which may be to VR or RQ, as the Velocity of the Planet is to the Velocity of the Earth: At the Center R, upon the Diameter VQ, deſcribe the Semicircle V*b**d*Q, to which draw the Tangents B*b*, B*d*, and produce them till they meet with VQ produced in Σ and T; draw R*b*, R*d*; take ΣK equal *b*Σ, and TL equal to *d*T. Then I ſay, the Points K and L, are what were to be found. For becauſe of the Equiangular Triangles R*b*Σ and BPΣ, ΣP : PB :: ΣK : R*b* or RV, and by alternation of Proportion, ΣP : ΣK :: PB : RV; but by Conſtruction, PB is to RV as the Velocity of the Planet is to the Velocity of the Earth; and Σ*b* touches the Semicircle in *b*; wherefore its Square is equal to the Rectangle VΣQ, by *Prop.* 36 *Elem.* III. And ΣK is equal Σ*b*; therefore ΣK will touch the Orbit of the Earth in the Point K, by 37 *Prop. Elem.* III; therefore the Tangents of both Orbits ΣP and ΣK, are as the Velocities; and therefore a Planet in P, will appear Stationary, when the Earth is in K. In the ſame manner it may be ſhewed, that the Right-Lines PT and LT, are as the Velocities, and that LT touches the Orbit of the Earth in L. Laſtly, the Lines SK SL being drawn, will ſhew the Places of the Earth ſeen from the Sun, and the Angles KSP LSP are the Commutations. And if the Line SA be the Line of the *Apſides* of the Earth's Orbit, KSA and LSA, will be the Angles of the true Anomaly; and conſequently if any error be committed in ſuppoſing the Earth's Velocity, it can be moſt accurately corrected, by having the true Anomaly.

IT is a *Problem* of a very different kind, to define the Time when a Planet is to be Stationary, and its Solution cannot be had from common *Geometry*; yet the aforeſaid Dr. *Halley*, by an indirect Method, and an Approxition, has ſhewed how to find it. It is as follows.

WHEN the Time of a Station is to be accurately determined.

HAVING by the former Conſtruction, or a rude Calculation, or even from an *Ephemeris*, found out the Day of the Station, find out by the moſt perfect *Aſtronomical* Tables, for the Meridian of that Day, the Place of the Sun; as alſo the Planets *Heliocentrick* and *Geocentrick* Places, and the *Logarithms* of their diſtances from the Sun; and for to reduce their Motions to the ſame Plane, *Curtate* the diſtance of the Planet, and we have the Triangle S T P, from the Principles of *Aſtronomy*, where S in repreſents the Sun, T the Earth, and P the Planet. Draw T Q a Tangent to the Earth's Orbit, and P Q a Tangent to the Planet's Orbit, which meet in Q. Now if the real Velocities of the Planet and Earth are as P Q and T Q, or as the Sines of the Angles P T Q and T P Q, it is plain that the Planet is then in the Situation required; that is, it will be there Stationary.

HAVING now the diſtances S T, S P, we have the *Ratio* of their real Velocities, or of T*t* and P*p*. For the real mean Velocities of different Planets, that is, thoſe Velocities with which at diſtances equal to half the Tranſverſe Axes of the Orbits, they would deſcribe Circles, are in a reciprocal ſubduplicate Proportion of the Axes. And * the mean Velocity of any Planet, is to its Velocity in any other Point P or T, in a ſubduplicate proportion of its diſtance from the Sun, to its diſtance from the other *Focus* of the Ellipſe, which call reſpectively P F and T F: and putting R for half the Tranſverſe Axe of the Superiour Ellipſe, and *r* for half the tranſverſe Axe of the Inferiour, and then compounding the *Ratios*, the Velocity of the Inferiour Planet, will be to that of the Superiour, or T*t* to P*p* as $\sqrt{R \times SP \times TF}$ is to $\sqrt{r \times ST \times PF}$; and therefore we muſt have ready the Logarithm of this Ratio reduced to the Plane of the Ecliptick.

* See the *Theor.* Lect. XVIII.

FROM the ſame diſtances, we have likewiſe the Angles S T Q and S P Q; for the Radius is to the Sine of the Angle S T Q, as $\sqrt{ST \times TF}$ is to half the Conjugate Axis of the Orbit; and likewiſe the Radius is to the Sine of S P Q, as $\sqrt{SP \times PF}$ to half the Conjugate Axis of the

Planet's Orbit: or, which is more readily perform'd; ſay, as the diſtance of the Planet in its *Aphelion* is to its diſtance in the *Perihelion*, ſo the Tangent of half the Angle, by which it is diſtant from the *Perihelion*, to the Tangent of an Angle, which being ſubſtracted from the foreſaid half, leaves the Complement of the Angle S P Q to a Right, or its exceſs above a Right, as it happens that this Angle is acute or obtuſe. Reduce this Angle if it is needful to the Plane of the Ecliptick, and theſe things being done, ſubſtract the Angle S T Q from the Angle S T P, and to the Angle S P Q add the Angle S P T, and we ſhall have the Angles Q T P and Q P T; and if the Sines of theſe Angles have the ſame Proportion that the real Velocities have in the Points T and P, the eſtimation is right: But if not, take the difference of the Logarithms of each, or the error of the firſt Poſition. And if the Ratio of the Velocities be leſs than the Ratio of the Sines, we muſt diminiſh the Angle T S P, by adding or ſubſtracting a known Mean Angle, ſuch as will agree to one Days Motion; and the contrary is to be done, if the Ratio of the Velocities be greater. And by a Calculation juſt like the former, ſeek the Logarithms of the aforeſaid Ratios, for the Noon of the preceding or following Day, as the caſe requires. Then compare the differences of the foreſaid Logarithms, or the error of the firſt Poſition with the error of the ſecond; and the Sum of the errors, if they be of ſeveral kinds, or their difference if they be of the ſame ſort, will be to 24 Hours, as either of the errors to the time between the Point of Station and the Noon on which the aſſumed error was found. This is plain to thoſe who underſtand the Rule of Falſe.

IN this manner the Stations of the Planets may be obtained within a few Minutes. But for to take away the ſmall errors which may ariſe, by reaſon the Logarithms do not uniformly encreaſe as the Time, if any one pleaſes, he may

renew

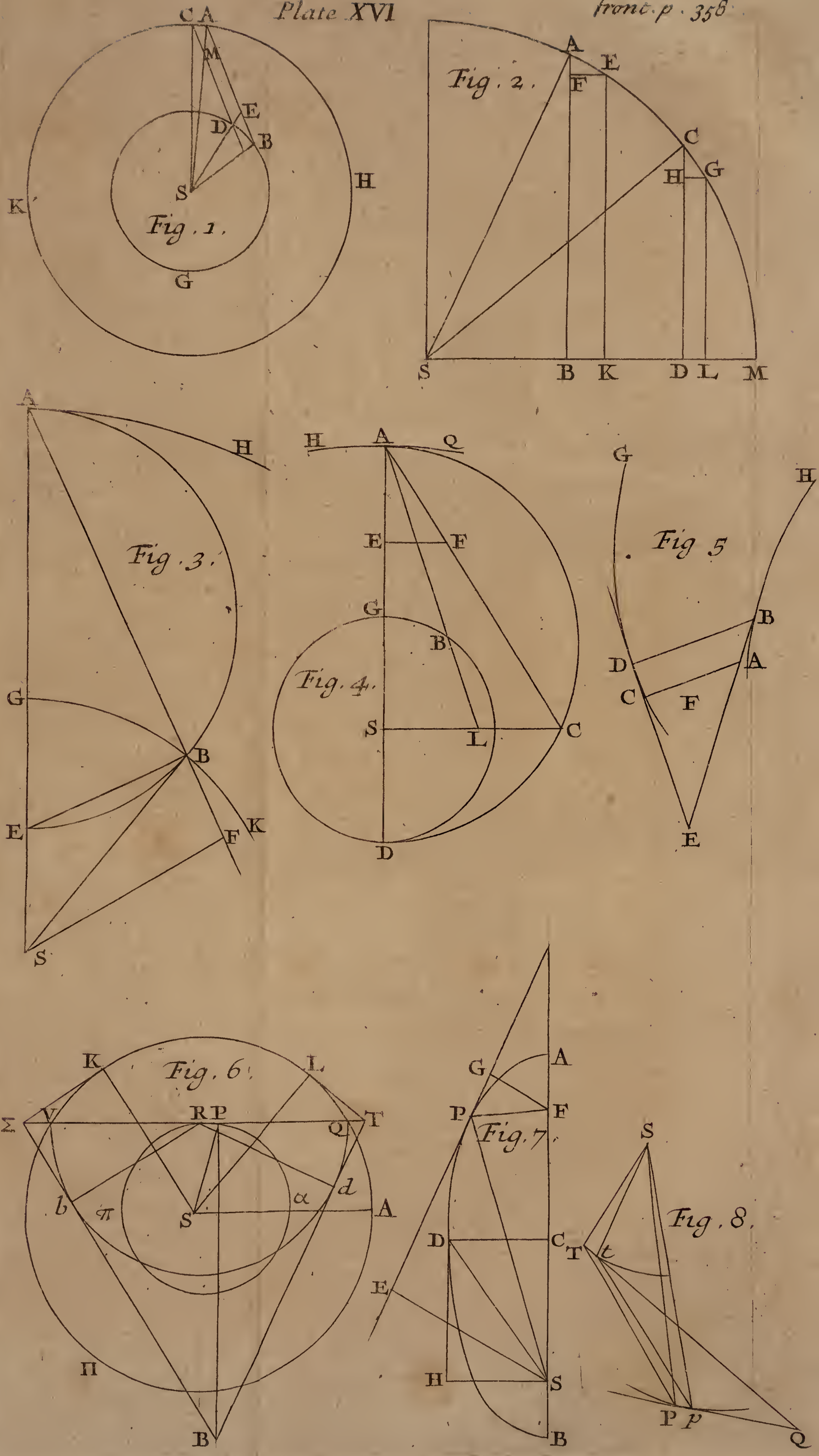
renew the Calculation, for the Time juſt found out, and which is very near the Truth, and ſo bring out the true Time to a Minute; but there is no need of this Correction but in *Mercury* or *Mars*.

FOR to make this plainer we will add an Example of the Station of *Jupiter*, which lately happened on *November* the 9*th* 1717.

November 9*th* at Noon.					*Nov.* 10*th* at N.			
	S	gr.	′	″	S.	gr.	′	″
The Mean Anom. of ♃	9	10	00	00	9	10	5	00
Mean Motion of ⊙	7	00	7	00	7	1	6	8
♃ Helio. from the 1 of ♈	2	25	11	00	2	25	15	53
⊙ Place from the 1 of ♈	6	28	53	17	6	29	54	00
Log. diſt. of ♃ from the Sun	5,720650				5,720680			
Log. diſt of ⊙ from the Sun	4,994267				4,994186			
♃ Geocentrick place	3	5	4	28	3	5	4	27
The Angle S T P		113	48	49		114	49	33
The Angle S P T		9	53	28		9	48	34
The Angle S T Q		89	23	54		89	23	54
The Angle S P Q		92	41	20		92	41	14
The Angle P T Q		24	25	42		25	25	39
The Angle T P Q		102	34	48		102	29	48
Log. of the Ratio of Velocit.	0,368210				0,368321			
Log. of the Ratio of the Sines	0,372912				0,356757			
The Error of the 1ſt Poſition	0,004702				0,011564			
The Error of the 2*d* Poſition	0,011564							

AND becauſe one of theſe Errors does exceed the Truth, and the other is deficient from it, ſay, as 16266 the Sum of the Errors, is to 4702, ſo is 24 Hours to 6 Hours 56 Minutes. Hence we conclude the Time of the Station of *Jupiter* to have been, *November* the 9*th*. Six Hours and 56 Minutes after Noon.

Plate XVI *front. p. 358*



LECTURE XXVIII.

Of the Diviſion of TIME, *and its Parts.*

A Natural Day.

THE Parts of *Time* are known to all Men, being Days, Hours, Weeks, Months and Years. A Natural Day is determined by the Apparent Motion of the Sun from Eaſt to Weſt, and is that Space of *Time* that flows while the Sun goes from any Meridian, or Horary Circle, 'till it arrives to the ſame again. It is called Natural to diſtinguiſh it from that ſignification of the word Day, which is oppoſed to Night, and which is called the Artificial Day.

The different Beginnings of the Day.

ALL Nations do not begin their Day alike. The *Babylonians* counted the Beginning of their Day, from the Sun riſing. The *Jews* formerly and the *Athenians*, from Sun ſetting; which the *Italians*, *Auſtrians* and *Bohemians* do at this time; ſo that when the Sun comes to the Weſtern Horizon, they count the Twenty-fourth Hour; and the Hour after the Sun is ſett, they call the firſt Hour.

THEY who begin their Day at Sun riſing, have this advantage, that their Hours tell them how much Time is already gone ſince Sun riſing; and they who reckon their Hours from Sun ſetting, have this uſe of it, that they know how long it is to Sun ſetting, that they may proportion their Journeys and Labours for that Time. But both of them have this Inconvenience, that they cannot immediately tell by their Hours the Times of Midday or Midnight, but they muſt compute by the length of the Day time, or the Seaſon of the Year; for in different Seaſons, the Time of Midday is reckoned by different Hours. The *Egyptians* antiently began their Day at Midnight, from whom *Hipparchus* that Antient and Famous *Aſtronomer*, brought that way of reckoning into *Aſtronomy*. And *Copernicus* and ſome other *Aſtronomers* have followed him therein. But the much greater part of the *Aſtronomers* have thought it better to begin their Day from Noon. Yet the Method of beginning from Midnight is received in *Britain*, *France*, *Spain*, and moſt of the Nations in *Europe*.

THERE are two ſorts of Hours, equal and unequal. An equal Hour is the Twenty fourth part of the Natural Day. Beſides the diviſion of Hours received by the Vulgar into half Hours, Quarters, and half Quarters, we now generally follow the *Aſtronomical* Diviſion, and reckon every Hour 60 Minutes, in every Minute 60 Seconds, and in every Second 60 Thirds, *&c.*

AN unequal Hour is the Twelfth Part of the Artificial Day, or the Twelfth part of the Night; and it is called the *Temporary Hour*, becauſe at different Seaſons of the Year, it is of a different Length. For a diurnal Hour in the Summer is longer than one in the Winter; a Night Hour is ſhorter. But in the Equinoctial Day, the Hours in the Day and Night are equal to each other; and therefore the equal Hours are called *Equinoctial*. The *Jews* and *Romans* formerly uſed theſe Hours, and the *Turks* reckon by them at this Day, and their Noon always falls upon the Sixth Hour of the Day. Theſe Hours are alſo called *Planetary Hours*, becauſe in every Hour they ſuppoſed one of the ſeven Planets to preſide over the World, and they took it by turns; ſo that the firſt Hour after Sun riſing fell on *Sunday* to the Sun; the next to *Venus*; the third to *Mercury*; and the reſt in order to the Moon, *Saturn*, *Jupiter* and *Mars*. By this means, on the firſt Hour of the next day the Moon preſided, and on that account gave the Name to that Day; and the Days of the Week by this Method have had their Names from the Planet that governed the first Hour, 'till the end of the Week.

Lecture XXVIII.

A Week.

A Week is a Syſtem of ſeven Days, in which each Day is diſtinguiſhed by a different Name. The Chriſtian Church called the firſt Day of the Week the *Lord's-day*, the Vulgar term it *Sunday*, and none but the *Phanaticks* of our Time, ever called it *Sabbath-day*. The reſt of the days of the Week were called *Feriæ*, *Munday* the ſecond *Feria*, *Tueſday* the third *Feria*, *&c.* and *Saturday* they alſo called the *Sabbath-day*. But the common People uſe the ſame Names that were given by the *Romans*; each Day being denominated from a Planet.

A Month.

A Month is properly that Space of Time the Moon takes to perform its Courſe in the *Zodiack*; which, in the Space of a Year, it runs over Twelve times. There is another Month nearly equal to it, which is meaſured by the Motion of the Sun, and is that ſpace of Time, in which the Sun moves through one Sign, or Twelfth part of the Ecliptick: Theſe Months are properly *Aſtronomical*. A Civil Month is different from them, and conſiſts of a certain number of Days, fewer or more, according to the Laws and Ordinances of the Kingdom or Republick in which they are obſerved. The *Egyptians* made each Month to conſiſt of 30 Days, and the Year conſiſting of 5 Days more than 12 Months, they added them to the end of the Year, and called them *Epagomenæ*.

The Civil Year of two ſorts.

THE Year is either *Aſtronomical* or Civil; both kinds of the *Aſtronomical* Years, *viz.* the *Tropical* and *Periodical*, we have already defined in our XXII *Lecture*. The Civil Year is the ſame with the Political Year eſtabliſhed by the Laws of a Country, and is of two kinds, Lunar or Solar, according as it is deſigned to be regulated by the Motions of the Moon or Sun. There are two ſorts of Lunar Years, the one

Lecture XXVIII

The moveable Lunar Year.

moveable, the other Fixed: The moveable Year conſiſts of Twelve Synodick Months, or of Twelve Lunations which are compleated in 354 Days, and after that time the Year begins again. This Year is leſs than the Solar Year, which brings back all the Seaſons by Eleven Days. And therefore the beginnings of ſuch Years move thro' all the Seaſons, and that in the ſpace of 32 Years: This Form of a Year is obſerved by the *Turks* and *Mahometans.*

The Fixed Lunar Year.

SINCE Twelve Lunations is leſs than a Solar Year by Eleven Days, three Lunar Years are leſs than three Solar Years, by 33 Days; and therefore to keep the Months in the ſame Seaſons and times of the Solar Year, to the third Year there is a whole Month added, and it conſiſts of 13 Months: And this is done as often as is needful, to keep the beginning of the Year always in the ſame Seaſon. And the Month added is called an *Embolimæan* or Intercalary Month. In nineteen Years there are ſeven ſuch Months, and this kind of Lunar Years are called Fixed, and were obſerved by the *Greeks*, whom the *Romans* followed in this matter 'till the times of *Julius Cæſar.*

The Solar Year.

THE Solar Year, which is made conformable to the Motion of the Sun, is likewiſe of two kinds, moveable and immoveable. The moveable is called the *Egyptian* Year, becauſe obſerved in that Country: and it conſiſts of 365 Days, and is leſs than the Tropical Year in which the Sun runs his Courſe in the Ecliptick, by almoſt ſix Hours. By the neglecting of theſe ſix Hours, it happens that four ſuch Years is leſs than four Tropical Solar Years by a whole Day: And therefore in four times 365 Years, that is, in 1460 Years, the beginning of the Years moves thro' all the Seaſons of the Year.

SINCE therefore an *Egyptian* Year is leſs than a true Solar Year, by almoſt ſix Hours; that all the Years may go on according to the Sun's Motion, a regard muſt be had to theſe ſix Hours. But it is requiſite alſo, that the Political Year have always the ſame beginning, and that it commence with the Day; for it would be inconvenient to have the Year begin ſometimes at one Hour of the Day, ſometimes at another; which would neceſſarily fall out if we added to every Year ſix Hours. Now theſe Hours amounting in three Years to Eighteen Hours, if they be added to the ſix Hours of the fourth Year, will make a whole Day: Therefore this Day being added to the fourth Year, will reduce it again to be even with the Motion of the Sun. *Julius Cæſar* perceiving this, ordered that every fourth Year ſhould have an Intercalary Day, which therefore conſiſts of 366 Days; and the Day added is put in the Month of *February*. And becauſe in the common Year the 24*th* of *February*, in the *Roman* way of reckoning, was the ſixth of the *Kalends* of *March*, or the ſixth Day before the *Kalends* of *March*, *Cæſar* ordered that for that Year there ſhould be two ſixths, or that the ſixth of the Kalends of *March*, ſhould be twice reckoned; upon which account the Year was called *Biſſextile*, which we name the Leap-Year. This Form of a Year was inſtituted by *Julius Cæſar*, who was then High-Prieſt among the *Romans*, and was called the *Julian* Year; whoſe nature is, that every fourth Year conſiſts of 366 Days, and the other three only of 365.

BUT it muſt be acknowledged, that the time appointed by *Julius Cæſar* for the Solar Year, is too much; for the Sun finiſhes his Courſe in the Ecliptick in 365 Days, 5 Hours and 49 Min. and therefore he begins again his round, Eleven Minutes before the Civil Year is ended. So that if the Sun in any Year has entered the Equinox upon the 20*th* of *March* at Noon-day, after 4 Years he will arrive at the Equinox 44 Minutes before Noon, and the fourth Year after that he will be there 1 h. 28 Min. before Noon; and ſo every Year 11 Minutes ſooner than by this reckoning; ſo that in 131 Years, he will anticipate or enter the Equinox a whole Day before the 20*th* of

March: And therefore the Cæleſtial Equinox will not always fall upon the ſame Day of the Month, but by degrees it will move towards the beginning of the Year: and this ſo ſenſibly in compaſs of time, that it cannot be doubted.

HENCE in the time of the Council of *Nice* (about which time, the Terms were ſetled for obſerving *Eaſter*) the Vernal Equinox fell upon the Twenty firſt of *March*: but the Equinox continually falling backwards in the Year, in the Year of *Chriſt* 1582, when the *Kalendar* was corrected, it was found that the Sun entered the Equinoctial Circle on the 11*th* of *March*, and was departed Ten whole Days from its former place in the Year: And therefore when *Gregory* the XIII of that Name, Biſhop of *Rome*, deſigned to place the Equinocties in their former Situation in reſpect of the Year; he took thoſe Ten Days out of the *Kalendar* that Year, and ordered that the Eleventh of *March* ſhould be reckoned as the Twenty firſt: And to prevent the Seaſons of the Year from going backwards as they did before; he ordained, that every Hundredth Year, which in the *Julian* Form was to be a *Biſſextile*, ſhould be a common Year, and conſiſt only of 365 Days; but becauſe that was too much, every fourth Hundred was to remain *Biſſextile*. This new Form of the Year being eſtabliſhed, by the Authority of the Biſhop of *Rome Gregory* XIII. is called by his Name the *Gregorian* Year, and is received in *France*, *Spain*, *Italy*, *Germany*, and in all the Countries where the *Pope*'s Authority is acknowledged; as likewiſe lately in ſeveral where the Reformed Religion is obſerved. Yet in *Britain* and other Northern Countries, the *Julian* Form of the Year is ſtill retained.

The Gregorian *Year.*

THE *Perſians* obſerve the *Egyptian* Form of the Years to this Day, whence it is that the Equinocties remain not in the ſame Month, but move thro' them all, and after a Period of about 1460 Years, the beginning of their Years falls in with the ſame time of the true Solar Year. This Time or Period is called the *Great Canicular Year*, or the *Sothiacal* Period, becauſe it takes its beginning on the firſt Day of the Month *Thoth*, or the firſt Day of that Year, when the Dog Star riſes Heliacaly, for the Word *Sothis* in the *Egyptian* Language ſignifies the Dog, which in *Greek* is called ἀϛροκύων, that is the Dog-ſtar, which the *Aſtronomers* Name *Sirius*.

THE Antients not only diſtinguiſhed the Times by Years, but by ſeveral Revolutions or Collections of Years; ſuch was the *Jubilee* of 49 or 50 Years; an Age conſiſted of a Hundred Years. But among the *Greeks* the *Olympiads* were eſteemed the moſt Famous, each of them containing the ſpace of four Years.

AS in the Heavens there are certain Points from which the *Aſtronomers* begin their Computations of the Planets Motions, ſo alſo there muſt be certain Points or Inſtants of Time, from which as from Roots, all Calculations muſt begin: and all Memorable Actions are diſpoſed and recorded, according to the Series of Years which follow from that Root. Theſe Roots are called *Epoch's* or *ERA*'s, from which we generally count our Years and Times. The moſt famous, beſt known, and moſt uſed by us, is that which is reckoned from the Nativity of our Lord *Jeſus*, which begins at the *Kalends* of *January* that immediately followed his Birth.

NOW altho' this *Epoch* is generally received by Chriſtians, yet the *Engliſh* and *Iriſh* have an *Epoch* a whole Year poſterior to it, which they commonly uſe in all Publick and Eccleſiaſtical Affairs: for they do not begin their Year with the firſt of *January* that follows the Nativity, but with the Feaſt of the Conception or Incarnation, which is obſerved on the 25*th* of *March*; and therefore it is that the *Engliſh* reckon from the Feaſt of *Lady-day* 1718, that there are compleated 1717 Years; but from the Birth of our Lord to the Feaſt of the Nativity of the Year 1717, they number only 1716 Years elapſed, whereas all the reſt of the Chriſtian World count 1717 Years.

The Author of the Æra.

IN this Affair they exactly agree with *Dionyſius* ſurnamed the leſs, according to whom *Chriſt* is ſuppoſed to have been conceived the 8*th* of the Kalends of *April*, in the firſt Year of this *ÆRA*; and was born the Winter following, at the end of the 46*th* Year from the Reformation of the Kalendar by *Julius Cæſar.* This way of computing was at firſt univerſally received, but afterwards by degrees and tacitely, all Nations receded from it; ſo that it does only now take place in *England*, and the Dominions thereof; and the common Opinion is that *Chriſt* was Born the Winter preceding the Time that *Dionyſius* reckoned the conception to have been; and by this means they make *Chriſt* to have been a Year before *Dionyſius* the Author of the *Æra* ſuppoſed he was Born.

BUT yet for all this the *Engliſh* for the greateſt part of the Year, deſign it by the ſame number that the reſt of the Chriſtian World does: but for three Months, *viz.* from the Kalends of *January* to the 8*th* of the Kalends of *April*, they write one Year leſs.

THERE is likewiſe the *Epocha* of the *Creation*, which is much noted, yet about it there are great Controverſies among the *Chronologiſts*; ſome affirming that the World was created 3950 Years before the Birth of *Chriſt*; others again ſay, that at the Birth of *Chriſt* the Age of the World was 3983 Years. The *Greek* Church and the Emperors of the Eaſt uſed an *Epocha* of the Creation, which was much more antient, and makes the World to have been Created 5509 Years before the coming of *Chriſt*.

AMONG the Prophane Authors, the Antienteſt *Epocha* is that of the *Olympiads*, which begun at the Summer of the Year 777 preceding the Birth of *Chriſt*, and on the Kalends of *July*.

THE *Epoch* of *Rome*, or of the Building of the City, is not long after the *Olympiads*, and there are two of them, the *Varronian* and *Capitolian*; according to the firſt, the City was built the Year before *Chriſt* 753; according to the other it was in the Year 752.

THE *Æra* of *Nabonaſſar* has always been famous among the *Aſtronomers*, and began on the 6*th* of *February* of the *Julian* Year carried backward, and before *Chriſt* 747. And becauſe that Day was then the firſt Day of the *Egyptian* Year, *Ptolemy*, and after him *Copernicus*, computed the Motion of the Stars according to that *Æra* by *Egyptian* Years; for the *Egyptian* Year is very convenient for *Aſtronomical* Calculations, it being interrupted by no intercalary Days.

AFTER this we have another *Epocha* of the Death of *Alexander* the Great, the three Hundreth and Twenty fourth Year before *Chriſt*, on the 12*th* of *November*; which was then the firſt Day of the *Egyptian* Year. *Theon*, *Albategnius*, and ſome others, have computed from thence according to the *Egyptian* Year. Between the two *Æras* of *Nabonaſſar* and of the Death of *Alexander*, there are preciſely 424 *Egyptian* Years. The *Abiſſines* reckon by another *Æra*, which is called the Æra *of the Martyrs or of* Diocleſian. The *Turks* and *Arabians* reckon by an *Æra*, which they call the *Hegira*, which takes its beginning from the flight of *Mahomet*. The *Perſians* have likewiſe an *Epoch* which they call *Ieſdegird*; all which are are explained by the *Chronologiſts*. But the *Julian* Period ſeems to be the moſt uſeful and convenient of all, it including almoſt all other *Æras* within it, and it is a Period of 7980 Years; which Number is compoſed by the Multiplication of the three numbers, 15, 19 and 28. The firſt is the *Cycle* of the *Indiction*; the ſecond is the *Metonick Cycle* of the Moon; and the third is the *Cycle* of the Sun. And the firſt Year of this Period was that wherein all theſe three *Cycles* began together. I will here add a Table, which gives the firſt Year of the ſeveral *Æras*, and reduces them to the Years of the *Julian* Period, and to the Years before, or after the Birth of *Chriſt*.

	Years before Chriſt	*Years of the* Julian *Period*
The Creation of the World, according to the *Greek* Emperors.	5508	
The Common *Æra* of the Creation.	3950	765
The Beginning of the *Olympiads*.	776	3938
The building of *Rome*, according to *Varro*	753	3961
The Building of *Rome*, according to the Regiſters of the Capitol.	752	3962
The *ÆRA* of *Nabonaſſar*.	747	3967
The Death of *Alexander* the Great.	324	4390
	Years after Chriſt.	
The common Chriſtian *Epoch*.	1	4714
The *Diocleſian Æra*.	284	4997
The *Hegira* of the *Turks*.	622	5335
The *Jeſdegird* of the *Perſians*.	632	5345

LECTURE XXIX.

Of the Kalendars. *Of* Cycles *and* Periods.

The Kalendar.

THE *Kalendar* is a Table, in which are ſet down all the Days of the Year, in a regular diſpoſition, according to their Months, with a diſtribution of them into Weeks. The Vigils, Holy-days and Law-days, together with the *Univerſity* Terms, are likewiſe annexed. The diſtribution of Days into Weeks, is made by the ſeven firſt Letters of the Alphabet, A B C D E F G. Beginning at the firſt of *January*, to it place the Letter A; to the ſecond of *January* B is joined; to the third C; and ſo on to the ſeventh, where G is figured: And then again beginning with A, which is placed at the Eighth Day; B will be at the Ninth; C at the Tenth; and ſo continually repeating the Series of theſe ſeven Letters, each Day of the Year has one of thoſe Letters in the *Kalendar*. By this means the laſt of *December* has the Letter A joined to it. For if the 365 Days which are in a Year be divided by ſeven, we ſhall have 52 Weeks, and one Day over. If there had been no Day over, all the Years would conſtantly begin on the ſame Day of the Week; and each Day of a Month would conſtantly have fallen upon the ſame Day of the Week. But now becauſe beſides the 52 Weeks in the Year, there is one Day more, from thence it happens that on whatever Day of the Week the Year begins, it ends upon the ſame Day; and the next Year begins with the following Day. For

The Dominical Letter.

Example, in a common Year of 365 Days, if the Year begin on a *Sunday*, it will end on *Sunday*; and the firſt Day of the next Year will be *Monday*.

THE Letters being ranked in this order; that Letter which anſwers to the firſt *Sunday* of *January* in a common Year, will ſhew all the *Sundays* thro'out the Year; and to whatever Days in the reſt of the Months that Letter is put, theſe Days are all *Sundays*; and therefore that Letter is called the *Dominical* or *Sunday* Letter of that Year. So alſo whatever Letter is joined to the firſt *Monday* in *January*, the ſame, as often as it is repeated in the *Kalendar*, ſhews the *Mondays* thro'out the Year.

IF the firſt Day of *January* be a *Sunday*, the laſt Day of the Year, as I have ſaid, will likewiſe be a *Sunday*; and therefore the next Year will begin on *Monday*, and the *Sunday* will fall on the ſeventh Day, to which is annexed the Letter G; which therefore will be the *Sunday* Letter for all that Year: And ſince the Year began on *Monday*, it will alſo end on that Day; and the following Year will begin on a *Tueſday*, and the firſt *Sunday* will fall upon the ſixth of *January*, to which Day is adjoined the Letter F, which is the *Sunday* Letter for that Year. And in the ſame manner for the Year next following, the *Dominical* Letter will be E: By this means the *Sunday* Letters will go in a retrograde order by G F E D C B A. In the Yearly *Kalendars*, which we call *Almanacks*, which is an *Arabick* Word, the *Dominical* Letter, for to diſtinguiſh it the better, is made a Capital, and all the reſt are of a ſmaller Form. By this means, at one view, we ſhall ſee all the *Sundays* in the Year.

IF all the Years were *Egyptian* Years of 365 Days, after a Period of ſeven Years, the ſame Days of the Month would return to fall on the ſame Day of the Week. But we obſerving the *Julian* Year, where every fourth is *Biſſextile* or conſiſts of 366 Days, in which beſides the 52 Weeks there are two Days over. If that Year ſhould begin with a *Sunday*, it will end on a *Monday*; and the next Year will begin on *Tueſday*, and the firſt *Sunday* of that Year will be on the ſixth of *January*, to which is annexed the Letter F, which will be the *Dominical* Letter for the Year following that Leap-year whoſe *Dominical* Letter was A.

BY this means, the *Biſſextile* Year returning every fourth Year, the Series of the *Dominical* Letters ſucceeding each other is interrupted, and does not return in order 'till after four times ſeven, or Twenty Eight Years. Hence ariſeth the *Cycle* of 28 Years, which is called the *Cycle* of the Sun; which being compleated, the Days of the Months return in the ſame order to the ſame Days of the Week. In this *Cycle* all the *Biſſextile* Years have two *Dominical* Letters, the firſt of which takes place till the 24*th* or 25*th* of *February*, and the other ſerves for all the reſt of the Year: For in the *Biſſextile* Year the 24*th* and 25*th* of *February* are eſteemed as one and the ſame Day, and both of them have the ſame Letter F annexed to them; and by this the order of the *Sunday* Letter is interrupted. For Example, if in the beginning of the Year, the *Sunday* Letter is E, the 24*th* of *February* will fall upon a *Monday*, and the 25*th* on a *Tueſday*; both which Days are marked with the Letter F; and therefore the following Letter G, which ſhewed the *Tueſdays* before, will now point out the *Wedneſdays*; and the next *Sunday* will fall upon the ſixth of *March*, to which in the *Kalendar* is annexed the Letter D; which will point out the *Sundays* for all the reſt of the Year, and then becomes the *Dominical* Letter.

The Cycle *of the Sun.*

THE firſt Year of the *Cycle* of the Sun is a *Biſſextile*, and the *Dominical* Letters anſwering to it are G and F. For the ſecond Year the *Sunday* Letter is E; for the third D; the fourth C; and again the fifth Year of the *Cycle* being a *Biſſextile*, has two *Dominical* Letters B and A; and ſo in the reſt. The following ſmall Table ſhews what *Dominical* Letter belongs to each Year of the *Cycle.*

1	G F	5	B A	9	D C	13	F E	17	A G	21	C B	25	E D
2	E	6	G	10	B	14	D	18	F	22	A	26	C
3	D	7	F	11	A	15	C	19	E	23	G	27	B
4	C	8	E	12	G	16	B	20	D	24	F	28	A

TO find the Year of the Cycle *of the Sun, for any Year of the Chriſtian* Era. To the current Year of *Chriſt* add 9, becauſe from the beginning of the *Cycle,* 'till the firſt Year of *Chriſt,* there were 9 Years paſt: Divide the Sum by 28, the Quotient ſhews the number of *Cycles,* that have revolved ſince the firſt Year before *Chriſt,* 'till the current Year; and the remainder, if there be any, is the current Year of the *Cycle*; but if there be no remainder, than 28 is the current Year of the Solar *Cycle.*

The moveable Feaſts.

BESIDES the fixed and ſettled Feaſt, which are always on certain and determined Days of the Year, there are other Feaſts and Holy-days, which are moveable, and in different Years fall upon different Days of the Month, and ſometimes in different Months: Theſe Holy-days are not regulated by the Motion of the Sun, but by that of the Moon: Such was the Feaſt of the *Paſſover,* inſtituted by God himſelf, for the *Jews* to obſerve; and is ſucceeded by the Chriſtian *Eaſter,* in Memory of our *Saviour*'s Reſurrection. God ordained that the Paſſover ſhould be Celebrated in the firſt Month, the 14*th* Day of the Month at Even. *See* Leviticus *Chap.* XIII. Now the *Jewiſh* Year was a Lunar Year, and ſo ordered by Intercalary Months, that the Month whoſe fourteenth Day, or whoſe full Moon, fell either on the Vernal Equinox, or next after it, was reckoned the firſt Month of the Year. The Chriſtian Church was willing to obſerve the ſame Method in celebrating of *Eaſter.* But yet to diſtinguiſhed it from the *Jewiſh* Paſſover, would not keep the Feaſt on the 14*th* Day, but

The Feaſt of Eaſter.

on the *Sunday* after, becauſe our Lord roſe upon the *Sunday* after the *Jewiſh* Paſſover.

THEREFORE for determining the time for the celebration of *Eaſter*, we muſt define the Time of the Equinox, which was believed to be fixed to the Twenty firſt of *March*, and the Fathers thought it could never happen on any other Day; and therefore they made their *Kalendar* upon that ſuppoſition. Then they called that the *Paſchal* or firſt Month, whoſe 14*th* Day or Full Moon fell on the Equinoctial Day, that is on the 21*ſt* of *March*, or next followed the 21*ſt* of *March*. But becauſe the *Jewiſh* Months were Lunar Months, the 14*th* Day immediately preceded the Full Moon; therefore for the Time of the Obſervation of *Eaſter*, we muſt have a regard to the Motion of the Moon, and the Times of New Moons and Full Moons muſt be found. The *Jews* had no other way of finding the New Moon, but by Obſerving it; and when the Moon firſt appeared to emerge out of the Sun's Rays, or to riſe in the Evening Heliacly, that Day they called the firſt Day of the Moon or Month. The Chriſtian Church computed their Lunations by the *Metonick Cycle* of 19 Years; and therefore they inſerted this *Cycle* in their *Kalendars*, and called its numbers the *Primes* or *Gold-numbers*, by which they determined the Times of the Lunations.

The Cycle *of the Moon*, *or the* Metonick Cycle

THE *Metonick Cycle*, called ſo from its Inventor *Meton*; is alſo termed the *Cycle* of the Moon, and is a Period of 19 Years, which when they are compleated, the New Moons and Full Moons return on the ſame Days of the Month; ſo that on whatever Days the New and Full Moons fall this Year, 19 Years hence they will happen on the very ſame Days of the Months, as *Meton* and the Fathers of the Primitive Church thought. And therefore at the Time of the Council of *Nice*, when the way of ſetling the Time for Obſerving the Feaſt of *Eaſter* was eſtabliſhed; the numbers of the Lunar *Cycle* were inſerted in the *Kalendar*; which upon the account of their excellent uſe, were ſet in Golden Letters, and the Year of the *Cycle* for any Year, was called the Golden Number of that Year.

THE Golden Numbers were placed in the *Kalendar*, according to the following Method; taking any Year for the beginning of the *Cycle*, which they reckoned by the number 1, and obſerving every Month the Days on which the New Moons happened that Year, juſt by thoſe Days they joined the Number 1. And becauſe in that Year the New Moons happened on the Twenty third of *January*, the Twenty firſt of *February*, the Twenty third of *March*; the Twenty firſt of *April*; the Twenty firſt of *May*; the Nineteenth of *June*, and ſo in the reſt; juſt by thoſe Days in the Column of the Golden Number, they put the number 1. The ſecond Year obſerving the New Moons, to the Days on which they happened they inſcribed the Number 2, *viz.* to the Twelfth of *January*; the Tenth of *February*; the Twelfth of *March*; the Tenth of *April*; and ſo on in the reſt of the Months. The ſame thing was done the Third Year, annexing the Number 3 to all the Days the Moon changed in that Year, and ſo on in the following Years, 'till the whole Period of 19 Years was compleated. But the moſt accurate diſpoſition of the Golden Numbers, is by the Mean Lunations, as they are ſett down in the *Aſtronomical* Tables, for every Month and each Year of the Lunar *Cycle*; And fixing according to that Computation the Character of the Year to each Day, on which the Lunation happens.

BECAUSE a Lunar *Aſtronomical* Month conſiſts of 29 Days, 12 Hours, 44 Minutes and 3 Seconds; the common People, who cannot diſtinguiſh the ſmall Particles of Time, do make the Lunar Months to conſiſt of intire Days without Fractions, and on that account they alternately put one Month of 30 Days, and the next of 29 Days, theſe are called Hollow or Cave,

that

Lecture XXIX.

that is, deficient Months, the others Full; the 12 Hours over the 29 Days requiring this alternation: But becauſe there are 44 Minutes beſides, which is almoſt three Quarters of an Hour in every Lunation, in 32 Lunations theſe Minutes will make up a whole Day, which is to be added to a Hollow Month, and by this means the Lunations of the *Kalendar* will nearly agree with thoſe of the Heavens.

IF we know the Year of the Lunar *Cycle*, which in our *Liturgy* is called the *Prime*, we have the Days of the Moons change thro'out the Year; for in each Month the Golden Number or *Prime* is ſet to the Day the change happens on; and adding to that 14 Days, we ſhall have the Day of Full Moon.

THE Antients imagined that the *Cycle* of 19 Years did exactly compleat 235 Lunations; and therefore after the Revolution of that Time, the New Moons not only fell on the ſame Days of the Month, but likewiſe on the ſame Hours of the Day, which is not true: For in 19 *Julian* Years there are 6939 Days and 18 Hours. But if to every Lunation we allow 29 Days, 12 Hours, 44 Minutes, 3 Seconds, which the Motion of the Moon requires; 235 Lunations will make 6939 Days, 16 Hours, 31 Minutes, and 45 Seconds. Therefore 235 Lunations are not equal to 19 *Julian* Years, but are leſs by one Hour and an half. And conſequently the New Moons after 19 Years, will not return to the ſame Hour, but will be an Hour and an half ſooner; and in 304 Years they will anticipate a whole Day. And therefore the Golden Number will, preciſely enough for common uſe, ſhew the Lunations in the ſpace of three Centuries, without the Error of one Day. In the Council of *Nice*, when the *Cycle* of the Moon was fitted to the *Kalendar*, and ſome Centuries afterwards, it did nearly enough give the Time of the New Moons. But the Lunations in every 304 Years, anticipating a whole Day, they now happen almoſt five Days ſooner than they ſhould do, according to the Rule of the Golden Number: Notwithſtanding of this, the Church of *England* retains the way of computing the Lunations by the Golden Number, as it was diſpoſed in the Kalendar at the time of the *Nicene* Council: And the New Moons computed in that manner are called Eccleſiaſtical New Moons, to diſtinguiſh them from the true ones, in the Heavens: And the general Table or Rule for finding *Eaſter* for ever, which is in our Liturgy, by the Golden Number and Dominical Letter, is made according to that Diſpoſition of the Golden Number.

IN the firſt Year of the Chriſtian *Æra*, Two was the Golden Number; and therefore if to the current Year of Chriſt we add 1, and divide the Sum by 19, the Remainder after the Quotient, will give the Golden Number.

FROM the *Cycles* of the Sun and Moon multiplied into one another, ariſes a third Period of 532 Years, which is call'd the *Victorian* or *Dionyſian* Period: And after the completion of this Period, not only the New and Full Moons return to the ſame Days of the Month; but alſo the Days of the Months return to the ſame Days of the Week; and therefore the *Dominical* Letters, and the moveable Feaſt's return again in the ſame Order. Hence this *Cycle* is call'd the great *Paſchal Cycle*.

FOR to find the Year of the *Dionyſian* Period for any Year of Chriſt, to the current Year add the Number 457, and divide the Sum by 532, the Remainder after the Quotient, is the Year of the Period.

IT is a *Problem* of another kind: *Having the* Cycles *of the Sun and Moon, to find the Year of the* Dionyſian *Period*. For Example, ſuppoſe the Year of the *Cycle* of the Moon to be 17, and of the Sun 21: For to ſolve this *Problem*, it is requir'd to find a Number, which, when it is divided by 19 leaves 17, and when it is divided by 28 leaves 21. For to find this, let it be requir'd to find two Numbers, one of which will divide exactly by 28, without a Remainder, but when it is divided by 19 leaves 17; and another Number which will divide exactly without a Remainder by 19, but when it is divided by 28 leaves 21: It is plain that the Sum of theſe two Numbers will anſwer the Queſtion.

WE will here ſhew the Analytical Inveſtigation of theſe two Numbers. We will ſuppoſe the firſt Number to be $28x$, for it is a multiple of 28; and becauſe this Number divided by 19 leaves 17; if we take 17 from it, the Remainder divided by 19 will be a Number; ſince then 19 divides $28x - 17$, and it alſo divides $19x$, therefore it will divide their Difference, which is $9x - 17$; conſequently $\frac{9x - 17}{19}$ is a Number. Call that Number n, conſequently $9x - 17 = 19n$, and $9x = 19n + 17$, and $x = \frac{19n + 17}{9}$ and becauſe x is an intire Number, 9 muſt divide $19n + 17$, but 9 divides $18n + 9$, therefore it will divide the Remainder $n + 8$, and therefore $\frac{n + 8}{9}$ is a Number. Let that Number be 1, and n will be $= 1$, and $x = 4$; conſequently $28x = 112 =$ to the firſt Number to be found. Suppoſe the ſecond Number to be $19y$, for it muſt be a multiple of 19, therefore $\frac{19y - 21}{28}$ is an integer Number; ſuppoſe it to be n, than $19y - 21 = 28n$, and $y = \frac{28n + 21}{19}$, which muſt likewiſe be an intire Number, and therefore $28n + 21$ will be divided by 19: But 19 divides $19n + 19$, wherefore it will divide the Remainder $9n + 2$, and $\frac{9n + 2}{19}$ is an intire Number: Suppoſe it $= p$ then is $9n + 2 = 19p$, and $n = \frac{19p - 2}{9}$

therefore 9 muſt divide $19p - 2$; but it divides $18p$, therefore it muſt alſo divide $p - 2$, and $\frac{p-2}{9}$ is an Integer or 0: Let it be equal to 0, then is $p = 2$ and $\frac{19p-2}{9} = n = 4$, and $19y = 28n + 21 = 133$; therefore one of the Numbers is 112, and the other is 133, whoſe Sum is 245, the Number requir'd: And whenever the *Cycle* of the Sun is 21, and that of the Moon 17, the Year of the *Dionyſian* Period is 245.

THE ſame *Problem* may be otherwiſe ſolved, by ſtated and conſtant Multiplicators, which are ſuch, that one of them can be divided by 28 without any Remainder, but if it be divided by 19 there remains 1: The other will divide by 19 without a Remainder, but when it is divided by 28 there is a Remainder of 1: Such Numbers are found in the ſame way as the preceding Numbers were, *viz.* I ſuppoſe the firſt to be $28x$, and the other $19y$; wherefore 19 will divide the Number $28x - 1$, without any Remainder, and therfore it will divide $9x - 1$ without a Remainder, and $\frac{9x-1}{19}$ will be a whole Number: Suppoſe it equal to n, then $x = \frac{19n+1}{9}$, therefore $\frac{n+1}{9}$ is an intire Number, and the leaſt Number that can be put for n is 8: Let therefore $n = 8$, and x being $= \frac{19n+1}{9}$ muſt be 17, therefore the firſt Number being $28x$, will be 476. Again, let $\frac{19y-1}{28} = n$, then $y = \frac{28n+1}{19}$; ſuppoſe $\frac{9n+1}{19} = p$, then is $n = \frac{19p-1}{9}$, and $\frac{p-1}{9}$ is either a whole Number or nothing; let $p - 1 = 0$, and $p = 1$, then $n = \frac{19p-1}{9} = 2$, and $19y = 28n + 1 = 57$. Therefore the two Numbers that were to be found, are 476 and 57. And becauſe the Number 476 divided by 19 leaves 1, if it be multiplied by any Number leſs than 19, and the Product be divided by 19, there will remain the Number which multiplies it. In like manner, becauſe 57 divided by 28 leaves 1, if 57 be multiplied by any number leſs than 28, and the Product be divided by 28, there will be left that Number which multiplied 57. Hence we draw this general Rule for finding the Year of the *Dionyſian* Period. Multiply the *Cycle* of the Sun by 57, and the *Cycle* of the Moon by 476; divide the Sum of the Products by 532, the Remainder after the Quotient will be the Year of the *Dionyſian* Period.

The Cycle of Indictions.

BESIDES the *Cycles* of the Sun and Moon, there is another Period of Years, which is called the *Cycle* of Indictions, which the *Romans* uſed, and has no Connection with the Celeſtial Motions, but is a Revolution of 15 Years, which being compleated, it begins again. It is frequently mentioned in the *Imperial* and *Pontifical Diploma's.* The Year before the Birth of Chriſt the Indiction was 3, and therefore if to the Year of Chriſt you add 3, and divide the Sum by 15, the Remainder ſhews the Year of the Indiction. If there be no Remainder, the Indiction is 15.

The Julian *Period.*

OF theſe three *Cycles* of the Sun, Moon, and Indiction, by their mutual Multiplication, the *Julian* Period of 7980 Years is compoſed. This Period had its beginning 764 Years before the Creation, and is not yet compleated, and therefore it comprehends all other *Periods*, *Cycles* and *Epoches*, and the Times of all memorable Actions and Hiſtories. There is but one Year in the whole Period, which has the ſame Numbers for the three *Cycles* of which it is made up; and therefore if the Hiſtorians had remark'd in their Annals the *Cycles* of each Year, there had been no Diſpute about the time of any Action.

From the Year of Chriſt to find the Julian *Period.*

THE Year before the Birth of Chriſt was the 4713th Year of the *Julian* Period. And therfore if to the current Year of Chriſt we add 4713, the Sum will be the Year of the *Julian* Period: On the contrary, from the Year of the *Julian* Period, ſubſtract 4713, there will remain the Year of the Chriſtan *Era*.

From the Cycles *to find the Year of the* Julian *Period.*

Having the Years of the *Cycle* of the Sun, Moon, and Indiction, to find the Year of the *Julian* Period.

This *Problem* may be ſolved in the ſame manner as we ſhew'd in the like Caſe about the *Dionyſian* Period, *viz*, by finding 3 Numbers, ſuch as the firſt is a Multiple of 19 and 15, or of their Product 285, but being divided by 28, leaves the Number of the *Cycle* of the Sun for a Reſidue. The ſecond Number muſt be a Multiple of 28 and 15, or of their Product 420, but being divided by 19 leaves the Year of the *Cycle* of the Moon. *Laſtly*, The third muſt be a Multiple of 28 and 19, but being divided by 15 leaves the Year of the Indiction: The Sum of theſe Numbers if leſs than 7980, is the Year of the *Julian* Period. But if the Sum be bigger, divide by 7980, and the Remainder will be the Year of the Period required.

THE *Problem* may likewiſe be ſolved by conſtant and ſtated Multiplicators, the firſt of which is a Multiple of the Number 285, but divided by 28 leaves 1. The ſecond is a Multiple of 420, but divided by 19 leaves 1 for a Reſidue. The third is a Multiple of 532, but being divided by 15 leaves for a Remainder 1. Theſe Numbers are to be found by the ſame Method we ſhew'd in our former *Problem*, concerning the *Dionyſian* Period, and are 4845, 4200, 6916; which being once found, the Canon or Rule for finding the Year of the *Julian* Period from the Years of the *Cycles*, is this; Multiply the Number 4845 by the Year of the *Cycle* of the Sun, and the Number 4200 by the Year of the *Cycle* of the Moon; likewiſe the Number 6916 by the Year of the Indiction. Divide the Sum of theſe Products by 7980, neglecting the Quotient, the Remainder will be the Year of the *Julian* Period required. Example. In the Year 1719, the Year of the *Cycle* of the

Sun is 19, of the Moon 9, and of the Indiction 11; multiply 4845 by 19, the Product is 92055, and 4200 being multiplied by 9, the Product is 37800; and laſtly, 6916 being multiplied by 11, the Product is 76076. The Sum of the Products is 205931, which being divided by 7980, will have a Remainder of 6431 Years, which is the Year of the *Julian* Period.

LECTURE XXX.

An Appendix containing a Deſcription and Vſe of both the Globes; *together with ſome Spherical* Problems, *that are to be ſolved by a* Trigonometrical *Calculation.*

OF the Things which pertain to the *Globes*, ſome are common to both *Globes*, ſome are peculiar to one of the Two: And thoſe Things that are common are either without the Surface, or painted on the Surface. Without the Surface of the *Globes*, are to be ſeen.

FIRST, the two *Poles*, about which the *Globes* revolve, the one is the *Arctick* Pole, named ſo from the two *Bears* that are nigh to it, and is called likewiſe the *Septentrional* or *North-Pole*, from the *Septem triones*, or the ſeven Stars of *Charles*'s Wain: The other oppoſite to it, is called the *Antarctick*-Pole.

SECONDLY, The *Brazen Meridian*, and one ſide of it only, which is diſtinguiſhed and divided into Degrees, and which paſſes through the Poles, repreſents the true *Meridian*; and this ſide is always to be turned to the Eaſt, and the *North-Pole* to the North. The *Meridian* is divided into four Quadrants of 90 Degrees, two of which are reckoned from that part of the Equinoctial that is above the Horizon, towards each of the Poles; the other two Quadrants have their Diviſions of 90 Degrees, beginning at the Poles and ending in the Equator,

THIRDLY, The wooden Horizon, whoſe upperſide does only repreſent the Horizon, and is divided into ſeveral Circles, the innermoſt of which contains the twelve Signs of the Zodiack, diſtinguiſhed by their Names and Characters, and each Sign is divided into 30 Degrees. Next to this is joyn'd two Circles, with the *Julian* and *Gregorian* Kalendars, diſpoſed according to their Months and Days. The outermoſt is a Circle with all the Points of the Compaſs, and the Winds as they are denominated by the Seamen.

FOURTHLY, A Braſs Quadrant of Altitude, whoſe Edge is divided into Degrees, and is to be faſten'd to the Meridian at the 90th Degree from the Horizon; from which the Degrees are number'd upon it upwards to the Zenith.

FIFTHLY, The Horary Circle divided into twice twelve Hours: The 12th Hour at Noon is upon the upper part of it, at the Meridian, and the 12th at Night is on the Meridian at the lower ſide towards the Horizon. The Pole carries round the Hand which ſhews the Hour, and is in the Center of the Circle: The Hours upon the Eaſt-ſide of the Meridian, are the Morning Hours, theſe on the Weſt-ſide are the Hours after noon.

SIXTHLY, The Mariner's Compaſs is fixed upon the Pediment or Wooden-Frame, which contains the Globe, and by it the Globe is put in a right Poſition in reſpect of the Points of the Heavens.

SEVENTHLY, The Semicircle of Poſition, whoſe Extremities are fixed to the Points of North and South, ſo that the Semicircle can be moved freely from the Horizon to the Meridian, and may be raiſed to any Poſition. Theſe things we have deſcribed are without the Globe. But on the Surfaces are delineated the things following.

FIRST, The Equinoctial Circle divided into 360 Degrees; the Numbers begin at the Vernal Interſection, or at the firſt of ♈, and are continued 'till they return to the ſame.

SECONDLY, The Ecliptick divided into 12 Signs, and each Sign into 30 Degrees, their Names, Characters and Order are to be learned: they are,

♈ ♉ ♊
Aries, or the *Ram.* *Taurus*, or the *Bull.* *Gemini*, or
♋ ♌
the *Twins.* *Cancer*, or the *Crab.* *Leo*, the *Lion.*
♍ ♎ ♏
Virgo the *Virgin.* *Libra* the *Balance.* *Scorpius* the
♐ ♑
Scorpion. *Sagittarius* the *Archer.* *Capricornus* the
♒ ♓
Goat. *Aquarius* the *Water-bearer.* *Piſces* the *Fiſhes.*

THE Sun in his annual Motion paſſes thro' the Ecliptick, and if we add to it a broad Space of about eight Degrees on each ſide, we have the Zodiack, in which are the 12 *Aſteriſms* or Conſtellations, the moſt of which have the likeneſs of ſome living Creature; upon which Account the Zodiack has its Name. In this broad Circle the Moon and all the Planets perform their Motions: The Ecliptick is to be diſtinguiſhed from the Equinoctial Circle by this, that the Equinoctial, while the *Globe* is turned, does always cut the Meridian and the Horizon in the ſame Points. But the Ecliptick conſtantly changes its Poſition; ſometimes while the *Globe* is turning it is high, ſometimes it is low, ſometimes it cuts the Equator and the Horizon in one Degree, ſometimes in another.

THIRDLY, There are the two Tropicks of ♋ and ♑, which are the Limits or Boundaries of the Sun's Deviations from the Equinoctial, either towards North or South, including between them the Oblique Courſe of the Sun, that is the Ecliptick, and may be called the outermoſt of the Sun's Parallels. For becauſe the Sun every Day paſſes to a different Degree of the Ecliptick in its Annual Motion, that Degree with the Sun in it, being carried round the Earth by the Diurnal Revolution of the Heavens, will deſcribe a Circle Parallel to the Equator, and then there muſt be ſo many Parallels, as there are Days from the longeſt to the ſhorteſt ; tho' the Sun does not remain for a Day in one Point of the Ecliptick, but is continually advancing forward ; and therefore does not deſcribe a perfect Parallel, but rather a Spiral Line : But the Diſtance between each Spire being but very ſmall, eſpecially near the Tropicks, we may well ſuppoſe the ſingle Revolutions, but eſpecially the outermoſt, to be Parallels ; which is ſufficient for common Uſe, and is moſt convenient

FOURTHLY, The two Polar Circles the Arctick and Antarctick, which have been explained in our VII and XVIII *Lecture.* Theſe things we have here mention'd, are common to both *Globes*, tho' the Ecliptick and the Semicircle of Poſition, do properly belong only to the Celeſtial *Globe*; yet they are put upon the Terreſtrial *Globe* alſo, that the Phænomena which depend upon the Motion of the Sun and the Points or Cuſps of the Houſes, may be thereby explain'd, if needful.

THOSE things which are peculiar or proper to one ſort of *Globe*, are Partly ſome Circles or Curve Lines, as in the Celeſtial *Globe*, the two *Colures*, and the *Circles* of *Latitude*. In the Terreſtrial the Meridian's, Parallels and Rumbs : Partly the Repreſentations in the Terreſtrial *Globe*, of Seas, Iſlands and Countries, which we leave to the Geographers to deſcribe. In the Celeſtial *Globe* the Figures of the Conſtellations are painted, and the Stars repreſented in the ſame Order, Magnitude and Poſition, they have in the Heavens. Theſe we have enumerated in our VII *Lecture.*

HAVING deſcribed the *Globes*, we come now to ſhew their Uſe, which is manifold; but for our preſent Purpoſe, it is chiefly contained in the following *Problems*. Lecture XXX.

PROBLEM I. *Having a place in the Terreſtrial* Globe, *to find its Longitude and Latitude.* Turn the *Globe* 'till the Place comes to the Meridian (I mean to the Eaſtern ſide of the Braſs Meridian) and the Degree of the Equator which is then under the Meridian, whatever Number it is mark'd by, ſhews the Longitude of the Place; then upon the Meridian count up from the Equator the Degrees mark'd, 'till you come to the Place, and you have the Latitude, which will be North Latitude, if the Place be on the North ſide; or Southern, if it lies upon the Southern ſide of the Equator.

PROBLEM II. *Having the Longitude and Latitude, to find out the Place on the Terreſtrial* Globe *to which they belong*: Seek in the Equator the Degree of Longitude that is given, and bring it to the Meridian; then count from the Equator on the Meridian the Degree of Latitude given, towards the Arctick or Antarctick Pole, according as the Latitude is either North or South, and under that Degree of Latitude lies the Place, that was to be found.

PROBLEM III. *To rectify both* Globes, *and ſet them to a given Latitude or Elevation of the Pole; and to apply the Quadrant of Altitude to the Vertical Point; and to place the* Globes *according to the Points of the Compaſs, by Help of the Needle.* If the Latitude of the Place be North, raiſe the Arctick Pole above the Horizon; But for a South Latitude, you muſt raiſe the Antarctick: Then from the elevated Pole, count upon the Meridian towards the Horizon, the Degrees of the Poles Elevation; and that Point where the Reckoning ends, bring to the Horizon, and then the *Globe* is adjuſted to a due Elevation. Count from the Equator on the Meridian the Latitude required, and there will be the Vertex of the Place, or the Zenith.

To

To this Point of the Meridian faſten the Quadrant of Altitude, with the Screw which is at the end of it, ſo that the Edge of the Quadrant which is divided into Degrees may be join'd to this Point. *Laſtly*, Turn the whole Frame in which the *Globe* is with its Pediment, 'till the Magnetick Needle lie in the Plane of the Meridian, ſo that the North Point of the Horizon of the *Globe* be turn'd Northwards; then will the reſt of the Points on the Horizon of the *Globe* agree with the correſponding Points of the Horizon of the Place.

PROBLEM IV. *To find for any Day of the Year the Degree or Place of the Sun in the Ecliptick, by the Help of the Kalendar, and the Circle of Signs adjoin'd; and then to mark it upon the Ecliptick.* Seek in the wooden Horizon, the Month and Day given, but take care to diſtinguiſh the *Julian* and *Gregorian* Kalendars, that you may not miſtake the one for the other: Then in the innermoſt Circle, which is the Circle of Signs, over-againſt the Day, you will ſee the Degree and Sign in which the Sun is that Day. In the Ecliptick which is drawn upon the Surface of the *Globe*, ſeek firſt the Sign, and then the Degree of the Sun's Place. The place of the Sun is more accurately found out by an *Ephemeris*, which is made for each Year, or elſe it may be calculated by *Aſtronomical* Tables.

PROBLEM V. *To find the right Aſcenſion and Declination of the Sun, or any Star; and by that means to adjuſt the Hand which points the Hours to the twelfth Hour.* Bring the Sun's Place in the Ecliptick, found by the laſt *Problem*, to the Meridian, and mark the Degree of the Equator which is then under the Meridian, that will be the right Aſcenſion of the Sun: Then compute from the Equinoctial on the Meridian, the Number of Degrees to the Place of the Sun, they will ſhew the Sun's Declination, which will either be North or South, as the Sun is on this or the other ſide of the Equator. When the Place of the Sun is in the Meridian, turn the Hour-hand upwards 'till it comes to the twelfth Hour at Noon. After the ſame manner bring the Place of any fixed Star to the Meridian, and you ſhall find its right Aſcenſion on the Equator, and its Declination on the Meridian. Having the Place of the Sun, we ſhew'd how to find its right Aſcenſion and Declination by *Trigonometry* in our XIX *Lecture.*

PROBLEM VI. *To find the Meridian Altitude of the Sun, or any fixed Star by a Quadrant, or any other Inſtrument fit for the Purpoſe.* We ſhew'd the Method of obſerving the Sun's or a Star's Altitude in *Lecture* XIX.

PROBLEM VII. *Having the Declination and Meridian Altitude of the Sun, or of a fixed Star, to find the Latitude of the Place or Height of the Pole above the Horizon.* The Method of finding the Latitude by Obſervation was likewiſe explain'd in *Lecture* XIX.

PROBLEM VIII. *Having the right Aſcenſion of the Sun and of a fixed Star: To find the Time when the Star culminates or comes to the Meridian.*

Subſtract the right Aſcenſion of the Sun from the right Aſcenſion of the Star, adding, if needful, 360 Degrees; and there will remain the Arch of the Equator that has paſſed the Meridian between Noon and the time of the Culmination: turn this Arch into Time, by dividing the Degrees by 15, and the Quotient gives the Hours; then multiply the remaining Degrees by 4, and you have the Minutes; and likewiſe divide the Minutes, which are the Parts of Degrees, by 15, and the Quotient gives the Horary Minutes: And if there be any Minutes of Degrees remaining after the Diviſion, multiply them by 4, and you have the Horary Seconds: The time made up of theſe Hours, Minutes and Seconds ſhews the Moment of the Culmination of the Star.

PROBLEM IX. *Having the Place of the Sun, or any Star, to find its Oblique Aſcenſion and Deſcenſion; as alſo its Eaſtern and Weſtern Amplitude.* Bring the Place of the Sun or Star to the Horizon in the Eaſt, and mark the Point of the Equator that riſeth with it; it will be its Oblique Aſcenſion: then count from the Point of Eaſt up-

Lecture XXX.

on the Horizon, to the Place of the Sun or Star ; the Degrees intercepted will be the Eaſtern Amplitude. If you bring the Place of the Sun or Star to the Weſtern ſide of the Horizon, the Degree of the Equator which goes down with it, is the Oblique Deſcenſion ; and the Arch of the Horizon between the Weſt Point and the Place of the Sun or Star, is the Weſtern Amplitude.

Table XXVI Fig. 3.

THE *Trigonometrical* Solution of the *Problem* is this: Let H P O P be the Meridian Æ Q the Equator, P the Pole, S the Sun, or Star in the Horizon, whoſe Declination is S R ; *or* the Point of Eaſt or Weſt. In the right-angled Triangle *or* R S, we have the ſide R S the Declination of the Sun or Star, and the Angle R *or* S, which the Equator makes with the Horizon, and is equal to the Complement of the Latitude ; whence we ſhall find the Arch *or* R, which is the Aſcenſional Difference of the Sun or Star ; which, added to the right Aſcenſion, or ſubſtracted from it, according as the Sun or Star is towards the depreſſed or elevated Pole, gives the oblique Aſcenſion. We ſhall have moreover in the ſame Triangle, the Arch *or* S, the Amplitude of the Sun or Star. The Aſcenſional Difference added to a Quadrant, or ſubſtracted from it, according as the Sun or Star is towards the elevated or depreſſed Pole, gives the Semidiurnal Arch ; which being turned into Time, ſhews the Time of half the Stay of the Sun or Star above the Horizon.

PROBLEM X. *Having the Aſcenſions of the Sun or Star, both Right and Oblique, to find the half Time of their Stay above the Horizon: As alſo the Length of Day and Night, and the Time of Sun-riſing and ſetting.* Take the Difference of the Oblique and Right Aſcenſion, and we ſhall have the Aſcenſional Difference : convert it into Time, as we ſhew'd in the VIIIth *Problem*, which, when the Sun or Star declines to the elevated Pole, is to be added to ſix Hours ; but if to the depreſſed *Pole*, it is to be ſubſtracted from ſix Hour ; and we ſhall have half the Time of the Stay of the Sun or Star above the Horizon: and its Complement to 12 Hours, is half the Time it abides under the Horizon: Half the Time of the Sun's Stay above the Horizon, being computed from Noon, gives the Time of Sun ſetting; and half the time of the Sun's Stay under the Horizon computed from Midnight, gives the Hour of the Sun's riſing; and the half Time of the Sun's Stay above the Horizon being doubled, gives the Length of the Day; and the half Time of the Stay below the Horizon doubled, gives the Length of the Night. If you put the Hour-hand to the 12th Hour, when the Place of the Sun is in the Meridian, and turn the *Globe* round, 'till the Place of the Sun comes to the Eaſtern ſide of the Horizon, the Hand will point out the Hour of Sun-riſing: Bring it to the Weſtern ſide of the Horizon, and the Hand will ſhew the Time of Sun-ſetting; from which it is eaſy to compute the Length of Day and Night.

PROBLEM XI. *Having the Time of the Culmination of a Star, and of its half Stay above the Horizon; To find the Hour of its riſing and ſetting.* If from the Time of the Star's Culmination, you ſubſtract the Time of the half Stay above the Horizon, you will have the Hour wherein the Star riſeth: If you add that Time to the Time of the Culmination, you ſhall have the Time of the Star's ſetting, which in both Caſes is computed from Mid-Day. Or, if when the Place of the Sun culminates, you bring the Hour-Hand to the twelfth Hour, and then turn round the *Globe*, 'till the Star comes to the Eaſtern or Weſtern ſide of the Horizon, the Hand will point to the Hour of the riſing or ſetting of the Star.

PROBLEM XII. *To find the Degree of the Ecliptick, which riſes or ſets with a given Star; and from thence to determine its Coſmical and Acronycal riſing and ſetting.* Bring the given Star to the Eaſtern or Weſtern ſide of the Horizon, and mark what Degree of the Ecliptick riſes or ſets with it; then in the wooden Horizon look for that Sign and Degree which roſe or ſet with the Star, and over-againſt it in the Kalendar, you will find the Month and Day of the Coſmical riſing of the Star. And if you look in the ſame Horizon the Point oppoſite to the riſing Point; over-againſt it in the Kalendar you ſhall have the Month and Day of its Coſmical ſetting. So likewiſe over-againſt the Degree that ſets with the Star, you will find the Day and Month of the Acronycal ſetting, and the oppoſite Degree will ſhew in the Kalendar the Day and Month of the Star's Acronycal riſing.

TableXXVI Fig. 3. THE *Trigonometrical* Solution of the *Problem* is this: Let H O be the Horizon, H Z O the Meridian, ÆQ the Equator, E C the Eclíptick. ♈ the Point of Interſection of the Equator and Ecliptick; A the Point of the Ecliptick which riſes with the Star, and the Point of the Equator which riſes with the Star, ſuppoſe to be *or*. In the Triangle ♈ *or* A, we have ♈ *or* the oblique Aſcenſion of the Star; and the Angle ♈ the Inclination of the Equator and Ecliptick; and the Angle ♈ *or* A, the height of the Equator above the Horizon, or its Complement to two right Angles. Hence we ſhall find the Arch of the Ecliptick ♈ A, and the Point of it A which riſes with the Star. But by the Kalendar, or an *Ephemeris*, we have the Time when the Sun is in that Point; and therefore we have the Time when the Star riſes Coſmically; we have likewiſe the Angle ♈ A, or the Angle of the Ecliptick and the Horizon at the riſing Point. When the Sun is in the Point oppoſite to the Point A, then the Star riſes Acronycally: And by a like Calculation, we ſhall find the Time the Star ſets Coſmically or Achronycally.

PROBLEM XIII. *Having the Latitude of the Place and the Degree of the Ecliptick which riſes or ſets with the Star; to determine the Heliacal riſing or ſetting of a Star.* Bring the Star to the Eaſtern ſide of the Horizon, and turn the Quadrant of Altitude round to the Weſtern ſide, 'till it cut the Ecliptick in the twelfth Degree from the Horizon, on the Quadrant of Altitude, if the Star be of the firſt Magnitude. Then mark the Point of the

Ecliptick where the Quadrant interſects it; that Point when the Star riſes is twelve Degrees high above the Weſtern Horizon, but at the ſame Time the oppoſite Point is twelve Degrees below the Eaſtern Horizon: Look that Point in the Wooden Horizon, and over-againſt it, you will find the Month and Day when the Sun enters that Point of the Ecliptick; which is the Day of the Star's riſing Heliacally; when it begins to get ſo far from the Sun's Beams, that it may be ſeen in the Morning before Sun-riſing. But if you would know the Heliacal ſetting: Bring the Star to the Weſt ſide of the Horizon, and turn the Quadrant of Altitude to the Eaſt ſide, 'till the 12th Degree of it from the Horizon cuts the Ecliptick, and mark that Point where it interſects the Ecliptick; the Point oppoſite to this is ſo many Degrees depreſs'd under the Horizon at the Weſtern ſide; and if we find, in the Wooden Horizon, the Month and Day when the Sun comes to that Point, we ſhall have the Time of the Heliacal ſetting.

Table XXVI. Fig. 3.

By *Trigonometry* the *Problem* is thus to be ſolved: In the Figure of the preceding *Problem*, let A be the Point of the Ecliptick, which riſes with the Star: And ſuppoſe the Sun in the Ecliptick at ⊙, ſo that the Arch ⊙ R of the Circle of Depreſſion may be 12 or 13 Degrees, according as the Star is of the firſt or ſecond Magnitude. In the right angled Triangle A R ⊙, we have the Angle R A ⊙ the Angle of the Ecliptick and Horizon, and the ſide R ⊙, which is 12 or 13 Degrees: Hence we ſhall have the ſide A ⊙, which added to ♈ A gives the Arch ♈ ⊙, and the Point ⊙, which the Sun muſt be in when the Star riſes Heliacaly. In the ſame manner we may find the Time of the Heliacal ſetting.

PROBLEM XIV. *Having the Latitude of the Place, and the Place of the Sun in the Ecliptick; To find the beginning and end of Twy-Light.* Rectify the *Globe* for the Latitude of the Place by *Problem* third, and put the Hour-hand to the twelfth Hour, the Sun's Place being in the Meridian;

then take the Point of the Ecliptick oppoſite to the Sun's Place, and turn the *Globe* Weſtward, as alſo the Quadrant of Altitude, 'till the Point oppoſite to the Sun's Place cut the Quadrant of Altitude in the 18th Degree above the Horizon: The Hour-hand will ſhew the Time of Dawning in the Morning. But if you take the Point oppoſite to the Sun, and bring it to the Eaſtern Hemiſphere, and turn it 'till it meets with the Quadrant of Altitude in the 18*th* Degree, the Hand will ſhew the Hour when Twylight ends in the Evening. The *Trigonometrical* Solution of this *Problem* is in *Lecture* XX.

PROBLEM XV. *Having the Latitude of the Place, and the Place of the Sun, if we have beſides any one of the three following things,* viz. *The Hour of the Day or Night; or the Altitude or Azimuth of the Sun or a Star: To find the other wo.* Rectify the *Globe* for the Latitude given, and bring the place of the Sun to the Meridian; and the Hour-hand to the Twelve a Clock Hour: Then if the Hour be given, turn round the *Globe* 'till the Hand points to it, and bring the Quadrant of Altitude to the place of the Sun or Star; you will ſee in the graduated Edge, the Degree of Altitude; and where the Quadrant interſects the Horizon, there you will find its Azimuth, to be counted from the Interſection of the Meridian and Horizon: But if the Altitude be given, turn the *Globe* with one Hand, and the Quadrant of Altitude with the other, 'till the place of the Sun meet with the Quadrant at the given Altitude; then the Hand will point to the Hour; and the Interſection of the Quadrant and Horizon will ſhew the Azimuth. But if the Azimuth be given, turn the Quadrant 'till it interſects the Horizon at the given Azimuth, and there keep it fixed; but turn the *Globe* 'till the place of the Sun or Star meets with the Quadrant, and the Degrees upon the Quadrant to the place of the Sun or Star, from the Horizon, will give the Altitude; and the Hour Hand will point to the Hour.

Lecture XXX.

Table XXV Fig. 4.

THE *Problem* is ſolved *Trigonometricaly* thus, Let H O be the Horizon, H P O the Meridian, Æ Q the Equator, Z the Vertex or Zenith, P the Pole, *S* the Sun or Star, whoſe diſtance from the Vertex is Z S, and S P the Complement of Declination, or its diſtance from the Pole. Becauſe we have the Right Aſcenſions of the Sun and Star, we have the difference of their Right Aſcenſions, which being turned into Time, will ſhew the Time of the Culmination of the Star; and the Arch which meaſures the Angle Æ P S, being turned into Time, will give the Hour of the Night. Now in the Triangle Z P S, having Z P the diſtance of the Zenith from the Pole, and PS the Complement of the Declination of the Star; if I have beſides theſe two the Angle P, which the Hour gives, we can from them find the Angle Z, which ſhews the Stars Azimuth, and the Arch Z S the Stars Zenith diſtance, which will ſhew the Altitude. Or if we have the Arch ZS, we ſhall find the Angle P, and by that the Hour of the Night; as alſo the Angle P Z S the Azimuth. Or if we have the Angle P Z S, we can from thence find Z S the Complement of the Altitude, and the Angle Z P S, which will give the Hour. By the ſame method having the Altitude of the Sun, which we take by an Obſervation, and his Declination, which is known by Tables from his place in the Eclipuick, we can find the Angle Æ P S, which being turned into Time, will give the Hour of the Day.

PROBLEM XVI. *To find the diſtance between two places on the Surface of the Terreſtial Globe.*

Let us for diſtinction ſake, call one of the places the firſt, and the other the ſecond. Rectify the *Globe* for the Latitude of the firſt place, and bring it to the Meridian, and there fix the *Globe* with the Quadrant of Altitude to the Vertex, and turn the Quadrant 'till its graduated Edge paſs thro' the ſecond place: Then count the Degrees of diſtance from the Vertex to the ſecond place: And the Arch of the Horizon intercepted between the Meridian and Quadrant will give you the Angle of Poſition.

Table XXVI Fig. 5.

BY *Trigonometry* we thus proceed. Let ÆQ be the Equator, P the Pole, S, *s* two places, whoſe Complements of Latitude are PS and P*s*; and becauſe their Longitudes are given, we have their difference of Longitude, which is meaſured by we Angle SP*s*: therefore in the Triangle SP*s*, the have the ſides SP, *s*P, with the Angle SP*s*: By them we can find S*s* in Degrees and Minutes, which being converted into Miles, allowing 69 Engliſh Miles for each Degree, we ſhall have their diſtance in Miles. We can alſo find the Angles PS*s* and P*s*S, which are the Angles of Poſition.

IN the ſame manner in the Heavens, if we have the Right Aſcenſions and Declinations of two Stars, or their Longitudes and Latitudes, we ſhall find their diſtances.

PROBLEM XVII. *For any Time and place, to erect the Theme or Scheme of the Heavens.* Rectify the Celeſtial *Globe* for the Latitude of the Place. If you have not a Celeſtial *Globe*, a Terreſtial will do. Take the place of the Sun for the given Time, and bring it to the Meridian, and the Hour-hand to the Twelfth Hour; then turn the *Globe* 'till the Hand ſhews the given Hour: Or if you like to be more accurate in your Work, to the Right Aſcenſion of the Sun add ſo many Degrees and Minutes, as the Time from Mid-day requires, for every Hour counting 15 Degrees, and for every four Minutes a Degree, rejecting, if it exceeds it, 360 Degrees; ſo by this you will have the Right Aſcenſion of Mid-heaven, or the Degree of the Equinoctial which then Culminates, which is to be placed under the Meridian. Then faſten the Semicircle of Poſition to the Meridian, at the Points of South and North in the Horizon. From the Point of the Equator culminating, count on the Equator 30 Degrees Eaſtward, and bring the Semicircle of Poſition to the 30th Degree, and obſerve in what Degree this Semicircle cuts the Ecliptick; that will be the Cuſp of the Eleventh Houſe, which muſt be ſet down on Paper. Again, move the Semicircle of Poſition to the 60th Degree of the Equinoctial from the culminating Point, and mark where it cuts the Ecliptick, and you have the Cuſp of the Twelfth Houſe, which is likewiſe to be writ down. Bring the Semicircle of Poſition to the Weſtern ſide, and count 30 Degrees from the culminating Point, and letting the Semicircle paſs thro' that Point, obſerve where the Semicircle cuts the Ecliptick; that will be the Cuſp of the 9th Houſe. Then count from the Culminating Point again Weſtward 60 Degrees, and the Semicircle of Poſition paſſing thro' that Point will cut the Ecliptick in the Cuſp of the 8th Houſe: and the Meridian cuts the Ecliptick in the Cuſp of the Tenth Houſe. And the place where the Horizon Eaſtward cuts the Ecliptick, is the Cuſp of the Firſt Houſe or the *Horoſcope*; And the Weſtern ſide of the Horizon ſhews in the ſame Ecliptick, where it cuts it, the Cuſp of the Seventh Houſe: and as it is Diametricaly oppoſite to the Firſt; ſo is the Second to the Eighth; and the Third to the Ninth; the Fifth to the Eleventh; and the Sixth to the Twelfth.

PROBLEM XVIII. *Having erected the Theme to direct any Point to any other Point.* To a Planet or Aſpect aſſign its place in the Zodiack, according to its Longitude and Latitude; and chuſe any Planet or Degree of the Ecliptick, which you would direct, and which, for diſtinction ſake, we will call the firſt Place; and the Place to which you would direct this firſt Place, call the ſecond: Then thro' the firſt Place, which uſed to be called the Significator, draw the Semicircle of Poſition, and mark that Degree in which it

Lecture XXX.

it cuts the Equator; then keeping the Semicircle in the ſame Poſition, turn the Globe Weſtward, 'till the ſecond Place arrive at it; and then again obſerve where the Equinoctial is cut by the ſaid Semicircle. Subſtract the Degree firſt obſerved, from the Degree obſerved in the ſecond; adding, if need be, 360 Degrees; the remainder is the Arch of Direction, which was to be found.

FINIS.

front. p. 396
Plate XXVI

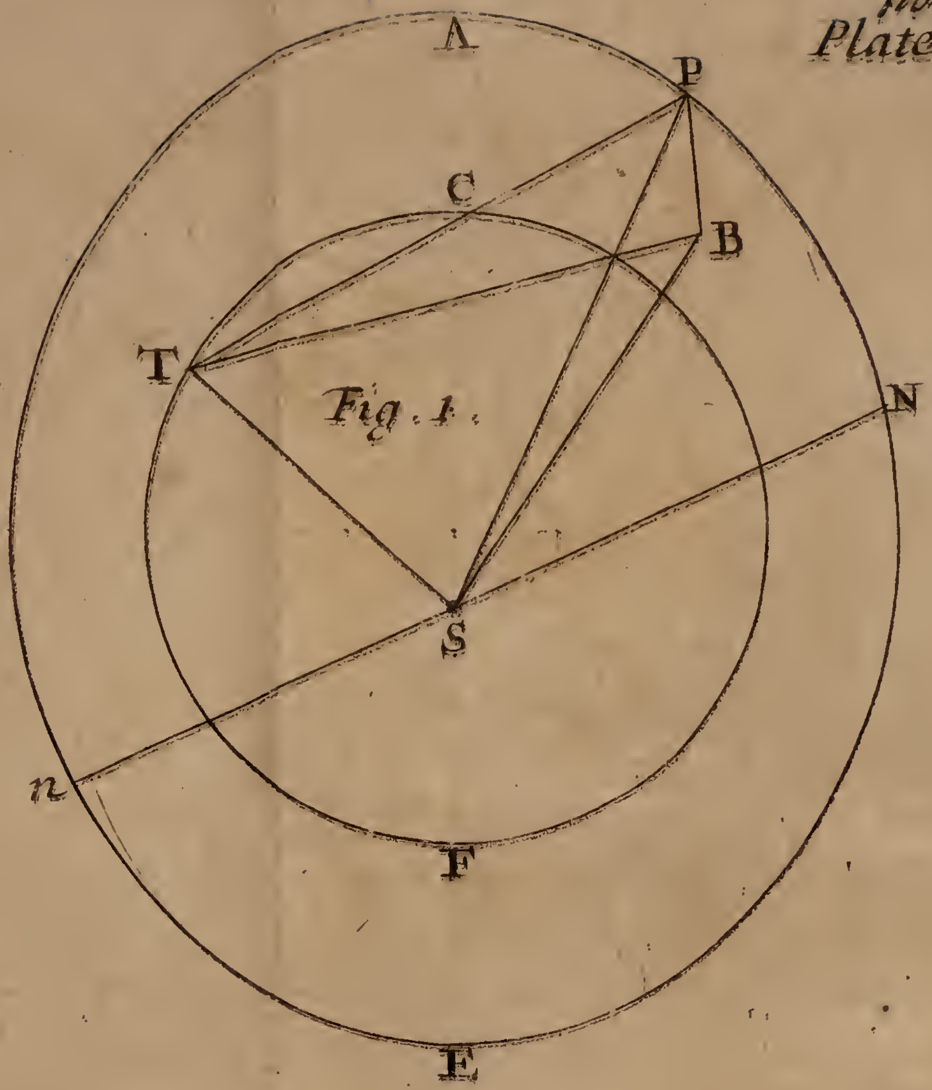


Fig. 1.

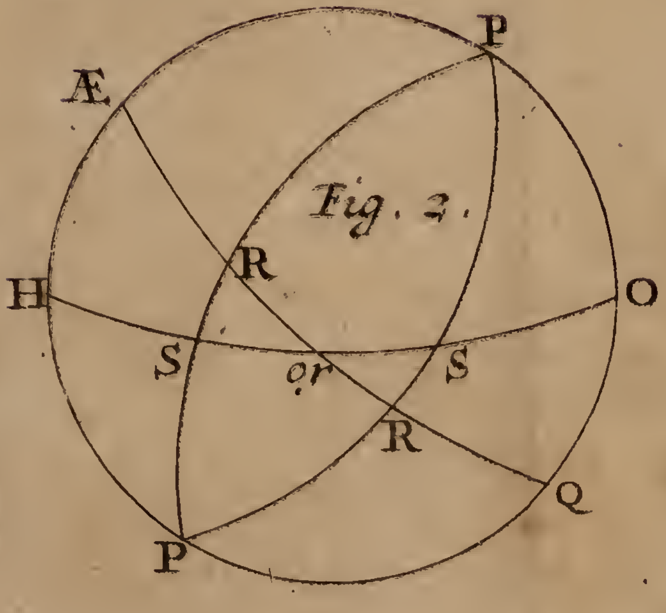


Fig. 2.

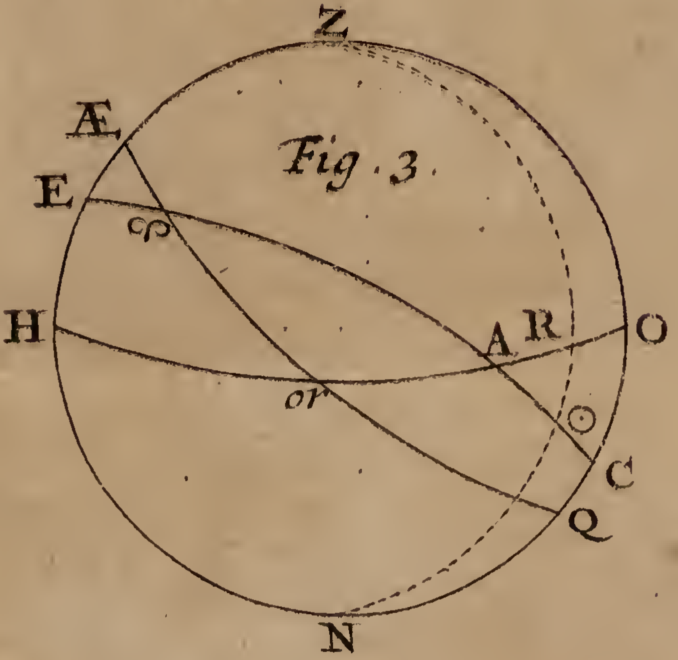


Fig. 3.

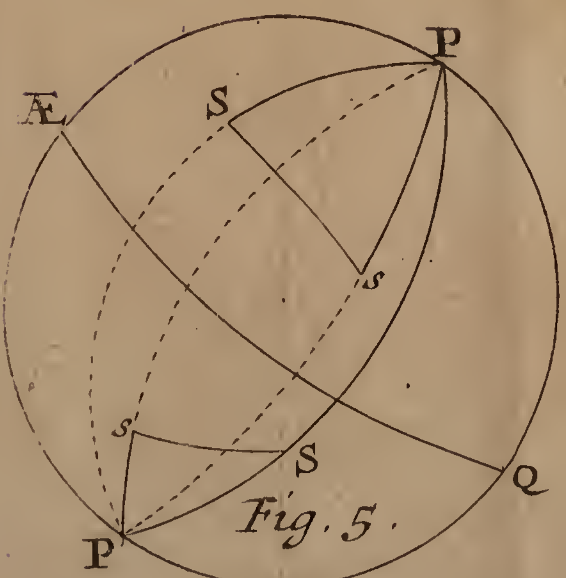


Fig. 5.

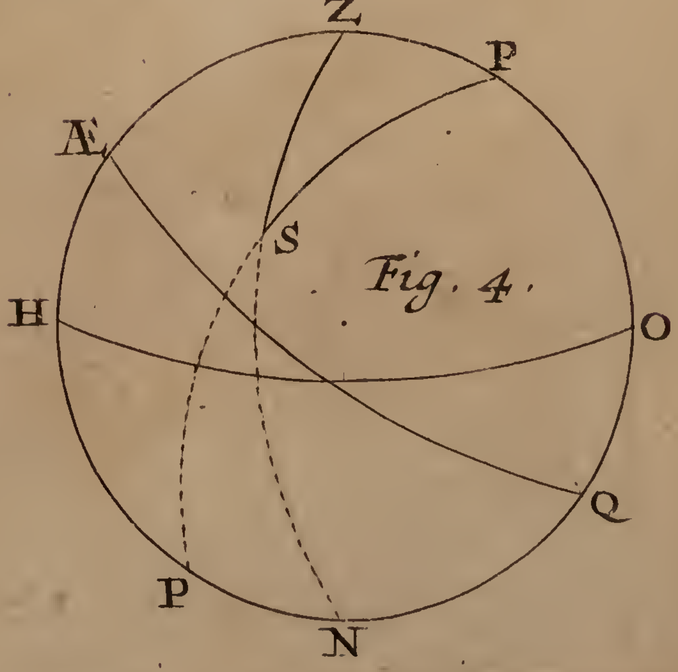


Fig. 4.

AN

INDEX,

Which ſheweth where the Terms and Words uſed in *Aſtronomy* are explained in this BOOK.

A.

Pag.

ABSIDS. See Apſides, [illegible]
Achronical riſing, 222
Æquation, what, 304
Where greateſt, 285
Æquation of Time, 317
Æquation of Time, when greateſt, 322
The Æquator or Æquinoctial, 63, 68, 208
Æquator's Secondaries, 74, 209
Æquinocties or Æquinoctial Points, 269
Alexander's *Death, an Æra,* 367
Altitude of the Pole, 217
  Of a Star, 6, 223
  Of the Earth's Shadow, 120
  Of the Moon's Shadow, Ibid.
Amphiſcii, 212
Amplitude, Eaſtern and Weſtern, 214
Amplitude of the World, 40
Anaſtraois Signs, 81
Andromeda, 49
Angles, their Meaſure, 4

Pag.
Method of obſerving, 5
The Angle under which the **Sun** *would appear ſeen from a fixed Star,* 37
The Angle of Commutation, 340
The Angle of the Æquator and the Ecliptick, 209
Of the Ecliptick and Meridian, 226
Of the Ecliptick and the Horizon, 267
Of the Ecliptick and Ventrical Circle, or the Parallactick Angle, 267
Anomaly, the Mean, 86
The True, 87
Of the Excentrick, 288
Anomaliſtical Year, 272
The Antarctick Circle, 70, 209
In Antecedentia, *a Motion,* 79
Antinous, 49
Antipodes, 211
Antœci, Ibid.
Aphelion, 85
Apogeon, 100
Its Motion, 102
Apparent Diameters, 6
Of the Sun, 82, 277
Apparent Diameters of the Moon's Shadow and Penumbra, 125
Apparition, 222
Of perpepual Apparition, the Circle, 220
Apſides, 85
Apus, *or the Bird of Paradiſe,* 50
Aquarius, *or the Water-bearer,* 49
Aquila, *or the Eagle,* Ibid.
Ara, *or the Altar,* 50
The ArctickCircle, 70, 209
Areas or Ecliptick Spaces equably deſcrib'd, 86, 278, 280
Argo *the Ship,* 50
Argument of Latitude,
Arius. *or the Ram,* 49
Ariſtarchus *his Problem to find the Sun's Diſtance,* 261
Aſcenſion right, 210
Aſcenſion Oblique, 220
Aſcenſional Difference, Ibid.

INDEX.

Pag.
Aſcii, *or Shadowleſs,* 213
Aſpect, Quadrate, or Quadrature, 93
Aſtronomical Tables, 339
Aſteriſms or Conſtellations, 48
Atmoſphere, its Advantages, 232
    Its Height, 236
    The Cauſe of Twilight, 233
    Of the Refraction, 240
Axis of the Earth, 63
    Its Paralelliſm, 66
    Axis of the Ecliptick, 73
Conſtellations, 48
Azimuths, 218

B.

Berenices *Hair,* 49
    Biſſextile Year, 363
Bootes, 49
Bulialdus *his Correction of* Ward's *Hypotheſis,* 306

C.

The Calculation of the Geocentrick Place of a Planet, 340
Cancer, *or the Crab,* 49
Capricorn, *or the Goat,* Ibid.
Cardinal Points, 67
Caſſiopeia, 49
Circle Æquinoctial, 208
    Of perpetual Apparition, 220
    Antarctick and Arctick, 209
    Of Azimuths or Verticals, 213
The Circle terminating Twilight, 236
Circles of Declination, 210
Circles, their Diviſion into Degrees and Minutes, 4
Circle the Ecliptick, 60
    Excentrick, 33, 273
    Horary, 216
Circle Horizontal, 6, 63, 213
Circles of Latitude, or Secondaries of the Ecliptick, 73, 207
The Circle bounding Light and Darkneſs, 65
Great Circles in the Sphere, 206
Leſs Circles, Ibid.
The Meridian Circle, 210

Pag.
The Circle of perpetual Occultation, 220
Circles Polar, 209
Tropicks, Ibid.
Circle prime Vertical, 213
Of Viſion, 92
Climates, 220
Colure of the Æquinoctiès, 210
Of the Solſtices, Ibid.
Comets, a ſort of Planets, 189
Their Courſe in the Heavens, 197
Their Figure, 195
Their Motion, 198
They demonſtrate the Neceſſity of a Vacuum, 203
The true Form of their Orbits, 198
Their Parallaxes, 192
Their Tails, 203
Commutation, 340
Conjunction of the Sun and Moon, 93
The Conical Shadow, 111, 116
Its Height, 120
Its Angle, 116
Conſtellations, 48
Copernicus *his Prophecy,* 163
Coſmical riſing, 222
Crater, *or the Cap,* 49
Crepuſculum, *or Twilight,* 233
Where ſhorteſt, &c. 239
Its different Durations, 228
Its Beginning and Ending, 240
Culmination, what, 214
Curtate Diſtance, 340
Cycle of the Moon, or the Metonick Cycle, 373
Cycle of the Sun, 371
Cycle of Indictions, 329

D.

Days Natural and Artificial, 39, 393
Days being longer than Nights, the Cauſe of hot Weather, 88
The inequality of Days, 314
The longeſt and ſhorteſt Days, when they happen, 326
Death of Alexander, *an Æra,* 367
Degrees, 5

Pag
Declination, 210
The Declination of the Sun, how obſerved, 125
Delineation of the Moon's Phaſis, 95
Diameters apparent, 6
  Of the fixed Stars, 37
  Of the Sun greater in Winter than in Summer, 82
Diameter of the Moon's Shadow, 125
  Of the Penumbre, Ibid.
  Of the Earth's Shadow, 125
Diameters of the Planets, 344
Dichotomy of the Moon, 93
Difference Aſcenſional, 220
Dionyſian *Period,* 376
Disk of the Earth, 128
Diſtance of the Sun, how to be found, 259
Diurnal Motion of the Sun, 272
Diurnal Mean Motion, Ibid.
Dominical Letters, 369
Dorado, 50
The Dog, Ibid.
Dragon, Ibid.
Dragon's Head and Tail, 99

E.

Earth, its Axis, 63
  Annual Motion, 60
  Poles, 63
  Diſtance from the Sun, 266
  Rotation round its Axis, 64
Eclipſes Explained, 109
Eclipſes of the Moon, when they happen, 111
  Of the Sun, when, 112
Eclipſes Total, Central, Partial, 113
Eclipſes Annular, 121
Eclipſes of the Earth, Ibid.
Eclipſes, their Limits, 124, 132
Ecliptick, 60, 207
  Its Secondaries, 113
  Obliquity, 225
  Axis and Poles. 73
Elevation of the Pole equal to the Latitude of the Place, 217
Ellipſis, its Deſcription, 84

Pag.

Its Focus *or Navel Point;* 85

Ecliptical Orbits of the Planets, 84

The Diviſion of the Ecliptick Area, 287

Elongation from the Sun, 94

Embolimæan Months, 362

Epocha, *or* Æra, 365

Equilus, *or the little Horſe,* 49

Eridanus, 50

Excentrick Circle, 83

Excentricity, 85

Excentricity of the Moon's Orbit Changeable, 102

Excentricity of the Planets Orbits, how found, 335

F.

Feaſts Moveable, 372

Fixed Soars, fiery Bodies and Suns, 39

Their Diſtinctions and Orders, 47

Their Number, 54

Their Catalogues, 51

Apparent Diameters, 37

Diſtances, 36

Right Aſcenſions, 227

Declinations, 225

Longitudes and Latitudes, 229

Riſings and Settings, 222

Refraction, 241

Fixed Stars, their Longitude, Increaſe, or their apparent Motion Eaſtward, 80

Foci, *or the Nevil-points of an Eclipſe,* 85

G.

The Glaxy or Milky way, 50

Gemini, *or the Twins,* 49

Geocentrick Place, 341

Geocentrick Latitude, 166

Globes, their Diſcription and uſes, 381

Grus, *or the Crane,* 50

Gyration of the Earth round its Axis, 63

The Gregorian *Year,* 364

H.

Harmony obſerved between the Diſtances and Periods of the Planets, 33, 341

Harp, 49

Heavens, they are not Fluid; 202

Pag

Their Matter Corruptible, 55

Heavens divided into Regions, 49

Heat why not greateſt when the Sun is in the Summer Tropick, 89

Hegeira the Turkiſh *Æra,* 367

Heliocentrick Place, 333

Heliocentrick Latitude, 332

Heliacal Riſing and Setting, 222

Hipparchus *firſt Compoſ'd a Catalogue of the fixed Stars,* 51

Hipparchus's *Problem for the Parallax of the Sun* 258

Hours, Equal and Unequal, or Planetary, 360

Horary Circles, 216

Horizon, Senſible and Rational, 213

The Poles of the Horizon, Ibid.

Horizontal Parallax of the Moon 123

I.

Ieſdegird, the Perſian *Æra,* 367

Images, or Conſtellations of the Antients, 49

Inequalities of the Moon, 101

The Inclinations of the Planets Orbits, to the Plane of the Ecliptick, 330

The Julian *Period,* 379

Indiction, a Cycle, Ibid.

The Julian *Year,* 363

Jupiter, *the Planet,* 155

Jupiter, *his Sattellites or Moons,* 181

Jupiter's *Belts and Spots,* 45

Jupiter's *Rotation round his Axis,* Ibid.

K.

Kalendar, 369

Kepler's *Elliptick Theory,* 278

Kepler's *Problem,* 287

L.

Latitude of a Star, 74, 208

Latitude of the Moon, 99

Latitude Geographical, 211

Latitude, how obſerved, 224

Latitude, Geocentrick and Heliocentrick, 174

Leo, *or the Lion,* 49

Libra, *or the Ballance,* Ibid.

Limits, 166

Line

Pag.

Line of Apſides, 85

Line of the Meridian, 224

Line of the Nodes, 99, 174, 331

Letter Dominical, 369

Longitude of a Place, 74, 210

Longitude, how to be obſerved, 148, 186

Longitude of a Star, 208

Longitude of the Stars, how found, 229

Light, its Motion demonſtrated, 841

Libration of the Moon, 103

M.

Magnitude of the Planets, 342

Mars, *the Planet,* 155

Mars, *his Parallax, double of the Sun's Parallax,* 265

Matter of the Heavens Corruptible, 55

Mean Diſtance, 85

Mercury, *one of the Planets,* 155

Meridian, a Circle of the Sphere, 210

Univerſal Meridian, 215

Meridian Line, how drawn, 224

Differences of Meridians, or of Longitude, 187

Metonick Cycle, 373

Midhaven, 215

Milky way, 50

Month, 361

Months, Synodical and Periodical, 97

Moon, an Attendant on the Earth, 90

  Its Apogeon and Perigeon, 100

  Diurnal Motion from the Sun, 98

  Elongation from the Sun, 94

  Its Face as drawn by Aſtronomers, 108

  Its Spots, Mountains and Cavities, 107, 108

  Its Libration, 103

  Illumination, and its Quantity, 95

  Its Light in total Eclipſes, 145

  Its Nodes, 99

  Eclipſes, 109

  Shadow, 118

  Its Diſtance from the Earth, 121

  Variation, 102

Motion, how viſible, 3

Motion of the Apogeon, 102

	Pag
Motions equable, why they appear unequal,	9
Motion Apparent of the Sun,	61
Motion of Comits,	196
Motion of a Ball falling in a Ship,	12
Motion of Light,	184
Motion in Longitude,	87
Mean Motion,	Ibid
Motion of the Nodes *backwards,*	99
Motion of the Planets round their Axes,	45
Motion of Venus *direct,*	169
Motion of Venus *Retrograde,*	Ibid.
The Radix, or Hepochs of Motions,	
N.	
Nabonaſſer, *an Æra,*	367
Nadir, *or the Vertical Points,*	213
New Moon,	93
Nodes *and the Lines of* Nodes,	99
Nodes, *their Retrograde Motion,*	99
Nonageſimal Degree of the Ecliptick,	215
Northern Hemiſphere,	208
O.	
Obliquity of the Ecliptick,	209
Oblique Aſcenſion,	220
Oculation,	222
Olympiads in Æra,	367
Optical Inequality,	10
Oppoſition,	92
Orion,	50
Orthographical Projection,	128
P.	
Parallel Circles,	206
Parallels and Climates,	222
Paralleliſm of the Earth's Axis,	66
Parallax of the Stars,	245
Parallax of the Moon,	123, 150, 257
Parallax of Altitude,	246
Of Longitude,	249
Of Latitude,	250
Parallax of the Annual Orb,	183
Parallax of the Sun,	258
Pavo, *or the Peocock,*	50
Pagaſſus, *or flying Horſe,*	46

Pag.
Panumbra, 118
Penumbra, *its Dimenſions,* 119
Phænix, 50
Periæci, 211
Perigeon, 100
Perihelion, 85
Periods of the Planets, 341
Periſcii, 213
Periœci, 211
Periods, Dionyſian, Julian, *and Sothaical,* 376, 379, 365
Perſeus, 49
Piſces, *or the Fiſhes,* Ibid.
The Phaſes of the Moon, 92
The Phaſes of Venus, 161
Place Geocentrick and Heliocentrick, 341
Place, its Poſition on the Earth's Disk for any given Time, 141
Place, its Longitude, 74, 210
Place of a Star reduced to the Ecliptick, 207
Planets, or Wanderers, 21
Planets, their order, 22
  Opake Bodies, 23
  They move round the Sun, 21
  Inferior, 155
  Superior, 177
Planets, Direct, Retrograd, and Stationary, 169, 178
Planets, their Diſtances from the Sun, compared with their Periods, 341
Planets Motion obſerved from the Earth are Irregular, 177
Secondary Planets, 22
Plenelunium, *or full Moon,* 92
Pole of the Eliptick or Heavens, 73
Poles of the Horizon, 213
  Of the World, 77
Polar Circles, 70, 209
Preceſſion of Æquinoctiæs, 80
Problem of Kepler's *Solved,* 289
Projection, Orthographical, 121
Projection of the Moons Shadow, 131
Proſthaphæreſis, 267

Pag.

Q.

Quature, or Quadrate Aſpect, 92
Quantity of the Year, 271

R.

Radix, or Epocha, 365
Reduction to the Ecliptick, 207
Refraction, 240
How to be obſerved, 242
Retrogradation of the Nodes, 99
Of the Planets, 169, 179

S.

Sagita, *or the Arrow,* 49
Sagitarius, *or the Archer,* Ibid.
Saturn, *a Planet,* 21
Saturn *his Ring,* 25
His Satellits, Ibid.
Scorpio, 49
Signs Twelve, Ibid.
Selenographers, 109
The Sun in the Center of our Syſtem, 23
His apparent Motion, 61
His apparent Motion unequal, 272
Sun's right Aſcenſion, Declination, and Longitude, how to be found, 225
The Sun turns round his Axis, 42
Sun's Axis inclined to the Plain of the Ecliptick, 44
Sun's Spots, 43
Spots of Jupiter, 44
Solſtices, 210, 269
The Setting of the Stars Coſmicaly, Achronicaly, and Heliacaly, 221
A Spectator is in the Center of his own View or Peoſpect, 19
Sphere right Oblique aud Parallel, 218, 219, 220
Stars are Suns, 39
Their Order and Bigneſs, 47
New Stars, 56
Stars which appear Periodically, Ibid,
Stars unform'd, 50
Stars, their Catalogues, 51
Their Number, 54
Stations, 169, 178, 345

Tables

T.

Pag.

Tables Aſtronomical, 337
Taurus, *or the Bull,* 49
Teleſcopes, their Advantages, 8
Theory of the Earth's Motion, 268
Theory of the Planets, 327
Time, its Equation, 312
  Its Parts, 393
Times of the Periods, 341
Triangulum, *or the Triangle,* 49
Tropicks, 69, 299

U.

The way of the Moon from the Sun, 125
Venus *a Planet,* 21, 155
Venus *ſeen in the Sun,* 29, 763
Venus, *her Phaſes,* 761
Venus, *her Brightneſs,* 165
  Her greateſt Elongation, 158
  Her two Conjunctions with the Sun, Ibid.
Virgo, *or the Virgin,* 49
Viſion, *how it is made* 2
Vertical Circles, 213
Vortices *in the Heavens, there are none,* 201
The World's Creation, an Æra, 366
Unformed Stars, 50

X.

Xyphias, *or the Sword-Fiſh,* 50

Y.

A Year,
  Aſtronomical, *Civil,*
  Tropical or Periodical. 361
  Lunar, Moveable or fixed 362
Year, Ægyptian, Ibid.
  Gregorian, 364
  Julian, 363
The great Canicular Year, 365
The great Year, conſiſting of 25920 Julian *Years,* 81

Z.

Zenith, 213
Zodiack, 207
  Its Breadth, Ibid.
Zones, *five in Number,* 212